TCRP SYNTHESIS 73

TRANSIT COOPERATIVE RESEARCH PROGRAM

AVL Systems for Bus Transit: Update

Sponsored by
the Federal
Transit Administration

A Synthesis of Transit Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

TRANSIT COOPERATIVE RESEARCH PROGRAM

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AVL Systems for Bus Transit: Update

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CONSULTANT
DOUG J. PARKER
TranSystems Corporation
Medford, Massachusetts

SUBJECT AREAS
Public Transit

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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 Transportation 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 TCRP includes a variety of transit research fields including planning, service 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 any time. 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 TRB. 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. The TCRP results support and complement other ongoing transit research and training programs.

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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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FOREWORD

By Staff
Transportation Research Board

Transit administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to the transit industry. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire transit community, the Transit Cooperative Research Program Oversight and Project Selection (TOPS) Committee authorized the Transportation Research Board to undertake a continuing study. This study, TCRP Project J-7, "Synthesis of Information Related to Transit Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute a TCRP report series, *Synthesis of Transit Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This synthesis documents the state of the practice, focusing on the uses of computer-aided dispatch/automatic vehicle location (CAD/AVL) systems in fixed-route and demand-responsive services (bus AVL), as well as changes in agency practices related to the use of AVL systems. The information will be of interest to transit agency managers, and maintenance, operations, planning, and business staffs, as well as other professionals involved in overall transit technology development. Information is presented on the characteristics of implemented bus AVL systems; agency experiences with designing, procuring, implementing, integrating, and using these systems; and on benefits and costs.

Information presented in this synthesis was obtained from a literature review, the responses from 32 transit agencies to a selected survey effort, and the findings from case study interviews.

Doug J. Parker, TranSystems Corporation, Medford, Massachusetts, collected and synthesized the information and wrote the paper, under the guidance of a panel of experts in the subject area. The members of the Topic Panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

AVL SYSTEMS FOR BUS TRANSIT: UPDATE

SUMMARY

This synthesis documents the state of the practice of computer-aided dispatch/automatic vehicle location (CAD/AVL) systems in fixed-route and demand-responsive services (referred to in this synthesis simply as bus AVL systems), as well as changes in agency practices related to the use of AVL systems. It provides a literature review, documents the results of a survey effort, and summarizes the findings from case study interviews. Also, information is presented on how transit agencies implement and use AVL systems as well as on benefits and costs.

For the purposes of this synthesis, a bus AVL system is defined as a core system with various common optional capabilities, as well as various common interfaces with other capabilities that are not treated as part of the AVL system (see Appendix B for additional detail).

- The core bus AVL system is defined as the central software used by dispatchers for operations management that periodically receives real-time updates on fleet vehicle locations. In most modern AVL systems this involves an onboard computer with an integrated Global Positioning System receiver and mobile data communications capability.
- Optional features, treated as part of the AVL system when implemented, include various features commonly integrated in commercially available AVL systems such as schedule adherence monitoring, onboard mobile data terminals, managed voice communications, text messaging, next stop announcements, and automatic passenger counting and real-time passenger information using dynamic message signs at selected stops.
- AVL systems also commonly include integration with various transit technology capabilities that are treated as not being part of the AVL system for the purposes of this synthesis (although the ability to support such interfaces is treated as part of the AVL system).

A survey questionnaire was prepared, which is presented in Appendix A for reference. The purpose of the survey questionnaire was to collect information from transit agencies on the characteristics of implemented bus AVL systems as well as agency experiences with designing, procuring, implementing and using these systems. The survey contained questions addressing the following areas:

- The technologies, timing, and scale of implemented bus AVL systems;
- Key issues experienced with designing, procuring, implementing, integrating, and using these systems; and
- Lessons learned.

The survey was distributed to 107 different transit agencies using an on-line survey software tool. Although not a comprehensive list of every agency with a bus AVL system, each of the agencies invited to participate were anticipated to have experience with a bus AVL system and represented agencies from throughout the United States as well as internationally. There were 32 survey responses.

It is important to understand and plan for how AVL systems are implemented and used by the various agency business units as well as the effects that implementing bus AVL will tend

to have on operations, including practices, organization, and staffing. It is also necessary to involve these business units accordingly in the system acquisition activities and once the system is in revenue service. Business units throughout an agency are involved in a variety of ways in AVL system implementation and use, including:

- Operations
  - Significant changes to communications between operators, supervisors, and dispatchers.
  - Substantial improvements in overall situational awareness for dispatchers and supervisors.
- Maintenance
  - The need to support new types of equipment, which in the case of dynamic message signs will extend to requiring an extended mobile maintenance capability.
  - Determining the most effective onboard maintenance data to collect, based on specific triggering conditions, both for onboard storage and real-time transmission.
- Customer service
  - Effective use of real-time and historical data for addressing customer questions and issues, including strategies for communicating with passengers about real-time information (e.g., incidents and next arrival predictions for stops).
- Security
  - Improved information on the location and situation of vehicles reporting a security incident.
- Information technology
  - Increased scope and scale of existing activities for supporting networks, servers, workstations, applications, databases, systems integration, and software upgrades.
- Planning
  - Making effective use of new comprehensive data sources in scheduling and performance analysis, including passenger counts, running time, dwell time, and schedule adherence.
- Revenue
  - Taking advantage of the potential for an onboard farebox interface.
- Marketing
  - The need to introduce and promote the new system for the public.
- Training and human resources
  - System will be a major source of required training on an ongoing basis.

There is a critical leadership role for top management to present the vision for overall transit technology development at the agency and why these technologies are being implemented. An AVL system needs an executive-level project champion as the sponsor to ensure that the initiative has access to the required resources, training, and staff for both implementation and operation. This top management backing is particularly critical for an AVL system to facilitate the cooperation and information gathering that is required and that must span numerous agency business units that do not normally need to interact on a day-to-day basis. Dedicated project management staffing, including consulting support, is necessary to provide the needed technical expertise and coordinate project activities.

Industry experience is that agency operating costs are not typically reduced through implementing an AVL system and may require that additional maintenance, information technology, and planning resources to achieve full value from the system. The considerable value in implementing an AVL system arises from its ability to improve service, gather more comprehensive and accurate data, support new passenger amenities (e.g., next stop announcements and next arrival predictions at stops), and carry future increases in the scale of operations with the same staff or limited staff increases (which can be considered an operating cost savings in the sense of costs avoided).

The industry is in the midst of a gradual shift toward AVL system features becoming valued as an essential element of a quality "transit product" as seen by the public, transit agencies, government funding sources, and the media—analogous to the evolution toward certain other transit features becoming increasingly expected as the norm (e.g., air conditioning and shelters at high-volume stops). The essence of this shift is that increasingly over time it becomes necessary to justify why an agency is not including the feature rather than justifying whether it should. The industry does not yet seem to be at such a tipping point, and it is not certain that this shift will occur. However, it is becoming more common for agencies to consider an AVL system in part because one has been implemented successfully by some of the agencies considered its peers. The challenge is to avoid believing that an AVL system will be a "magic bullet" that can accomplish far more than is realistic (or justifying the system on such a basis), because this creates unrealistic expectations for the initiative.

Expected benefits of a bus AVL system for fixed-route operations include:

- AVL software provides improved situational awareness and additional voice communications management capabilities for dispatchers, extending the size of fleet that can be handled by each dispatcher.
- The transmission of schedule adherence feedback to dispatch, operators, and supervisors helps to maximize on-time performance and reliability.
- AVL helps dispatchers and supervisors to be proactive in addressing operational issues, including more timely and effective reaction to service disruptions.
- Text messaging can improve dispatch efficiency and provide clearer messages in distributing information to operators.
- Covert alarm monitoring supports the ability for operators to quickly inform dispatch about an onboard emergency and for dispatch to immediately know the vehicle location to send assistance.
- A single point for operator login to all onboard equipment reduces the potential for inaccurate login, maximizing the accuracy of schedule adherence, headsigns, and farebox data.
- Automated next stop announcements provide consistent announcements for passengers, reduce operator workload so they can focus on safe vehicle operation, and help address the requirements of the Americans with Disabilities Act.
- Automatic passenger counting equipment allows for the cost-effective collection of comprehensive passenger boarding and alighting data with consistent reliability compared with the use of human ridecheckers.
- AVL can provide real-time next bus predictions to customers both pre-trip and enroute, which can help increase ridership by reducing customer anxiety, enhancing perceived reliability, and presenting a more "modern" image (in particular among "choice" riders).
- More comprehensive historical data collection and incident reporting allows more effective and detailed analysis (e.g., for Planning Departments to use historical schedule adherence data to develop schedule adjustments).

Expected benefits of a bus AVL system for paratransit operations include:

- Electronic manifests and trip completion data that reduces operator workload and provides more accurate and consistent data.
- Real-time fleet location data that further improves the ability of scheduling software to enhance vehicle productivity and accomplish integration with fixed-route service.
- Onboard navigation assistance aids operators in keeping on schedule, in particular with newer operators who are less familiar with local streets.

This synthesis includes a review of capital costs for 27 different recent contract awards in the United States and Canada, dating from 2001 to 2007, and involving purchases from most of the established major systems integrators for bus AVL systems. A linear model was calculated for how contract award value increases with fleet sizes, with the following calculated equation of best fit for fleet size less than 750 vehicles (the available data for larger fleet size procurements did not support the development of a linear model):

- Contract Award = \$17,577(Fleet Size) + \$2,506,759 (with an $R^2 = 0.67$).

The formula should be used only as a rough approximation of expected capital costs for any given project, owing to the limited sample size and the numerous specific factors affecting procurement costs that are not captured in this model that only varies with fleet size. As noted earlier, these additional factors include:

- The competitive situation for the particular procurement,
- The specific scope of the procurement (in particular, whether significant capital cost items such as radio system enhancements or a real-time passenger information system are included), and
- The effects of inflation of system prices over time (which may not match general price increases owing to inflation in the overall economy as a result of the ongoing price stability or even decreases in prices for computer hardware and software over time).

Nonetheless, this equation helps quantify the general magnitude for capital cost, a central systems element that is relatively insensitive to the fleet size, and a component (e.g., for onboard systems) that is relatively proportional to fleet size.

CHAPTER ONE

INTRODUCTION

PROJECT BACKGROUND AND OBJECTIVES

TCRP Synthesis 24: AVL Systems for Bus Transit, published in 1997 (*1*), addressed various aspects of developing and deploying automatic vehicle location (AVL) systems over the previous 20 years. It discussed practice at that time, AVL architecture and technologies, and the institutional context of AVL defined in terms of funding, justification, staffing, and procurement. Much has happened over the past 10 years for the implementation of these systems. As more transit agencies acquired AVL systems and collected real-time vehicle location data, an update was needed.

This synthesis documents the current state of the practice, focusing on the uses of AVL systems in fixed-route and demand-responsive services, as well as changes in agency practices related to the use of AVL systems. Information has been gathered on effects, benefits, and costs to transit agencies.

TECHNICAL APPROACH TO PROJECT

A literature review focusing on the current state of the practice in bus AVL systems was conducted using a variety of sources.

A survey questionnaire was prepared, the purpose of which was to collect information from transit agencies on the characteristics of implemented bus AVL systems as well as agency experiences with designing, procuring, implementing, and using these systems (the questionnaire can be found in Appendix A). The survey contained questions addressing the following areas:

- The technologies, timing, and scale of implemented bus AVL systems;
- Key issues experienced with designing, procuring, implementing, integrating, and using these systems; and
- Lessons learned.

The survey was sent to 107 different transit agencies. All the agencies invited to participate were believed to have experience with bus AVL systems and included agencies from throughout the United States and internationally. Thirty-two survey responses were received. There were several rounds of follow-up, and it was judged that further attempts to elicit additional responses would not be fruitful and fit within the project schedule. In addition, the received responses were considered to represent a range of agencies in terms of both fleet size and location. A summary of these responses and a list of the responding agencies are provided in chapter three.

More detailed case study interviews were conducted with the following four agencies, which were selected to provide diversity in geographic location, fleet size, system integrator, and AVL system functionality:

- Beaver County Transit Authority, Rochester, Pennsylvania (Pittsburgh region).
- King County Metro, Seattle, Washington.
- Triangle Transit Authority, Raleigh–Durham, North Carolina.
- Valley Metro, Phoenix, Arizona.

REPORT ORGANIZATION

Information gathered through the literature review, survey responses, and case study interviews have been summarized and organized for presentation in this synthesis in the following sections:

- Chapter two—Review of literature
  - Summary of key elements of the background literature are reviewed.
- Chapter three—Summary of survey results.
- Chapter four—Case studies of the AVL system experiences at selected transit agencies.
- Chapter five—Discussion of how AVL systems are implemented and used by transit agencies, addressing effects on business practices, organization, and staffing in the acquisition and revenue service phases, for various parts of the overall agency organizations including:
  - Operations,
  - Maintenance,
  - Customer service,
  - Security,
  - Information technology,
  - Planning,
  - Revenue,
  - Marketing, and
  - Training and human resources.

- Chapter six—Benefits and costs
  - Quantitative and qualitative benefits, and
  - Capital and operating costs.
- Chapter seven—Conclusions.

Appendix A is the survey questionnaire; Appendix B provides an overview of current bus AVL systems; and Appendix C discusses the systems engineering process as it applies to the design and implementation of AVL systems.

OVERVIEW OF BUS AUTOMATIC VEHICLE LOCATION SYSTEMS

This section provides a brief overview of the technologies used in bus AVL systems, the functional capabilities available, and integration with other agency systems. Appendix B provides a more detailed review on this topic.

Bus AVL systems have been and continue to be a significant area of activity for transit agencies in North America and elsewhere, as well as for systems integrators that serve this market. In the 1970s and 1980s, an early generation of bus AVL technology using wayside "signpost" beacons as the location tracking method was first being adopted by agencies in North America. By the late 1990s, agencies were generally adopting AVL systems using the Global Positioning System (GPS), which became fully operational in 1995. GPS-based AVL systems addressed some of the key limitations of signpost-based AVL by eliminating the need to maintain the wayside signposts infrastructure.

Figure 1 shows an operator area of a fixed-route bus with a typical recent vintage AVL system, in this case for the system currently being used at Votran in Daytona Beach, Florida.

Figure 2 is an example of a typical fixed-route dispatcher AVL workstation, in this case for an AVL system in use for the VIVA BRT at York Region Transit near Toronto, Ontario.

FIGURE 1 Typical fixed-route operator area with an AVL system (black box) (*Courtesy:* Doug Parker, TranSystems).

FIGURE 2 Typical fixed-route AVL dispatcher workstation (*Courtesy:* Doug Parker, TranSystems).

Much of the focus of AVL systems deployment in recent years has been on increasing the overall capabilities, sophistication, and degree of integration involved. Although the basic system architecture used over the past ten years has not changed significantly, AVL systems have progressed remarkably in the degree of functionality and reliability available. There has been a trend toward increased integration between components and systems. This increasing degree of integration is being driven by the larger number of subsystems in modern AVL systems as well as the larger number of other types of technology deployed at transit agencies. Commercially available AVL systems have also increasingly been incorporating rapid advances that have become available in overall communications, computing, and networking technologies.

Today's bus AVL systems include both the core location tracking capabilities and the following additional options that are commonly included, as illustrated in Figure 3. There are various other functionalities also supported by current transit technology that have not been treated as part of bus AVL systems for the purposes of this synthesis.

- Ability to monitor additional "dead reckoning" devices to complement the GPS receiver in vehicle positioning—the most common being integration with the vehicle odometer, with another option being a heading sensor such as a compass or gyroscope.
- Managed voice communications, with dispatch initiating voice calls when needed and on receiving "Request To Talk" data request messages from operators (the voice communications system is not treated as part of the AVL system).
- Text messaging data communications between operators and dispatch.
- Single point of onboard logon by means of the operator terminal (e.g., headsign and farebox).
- Onboard next stop announcements triggered automatically as the vehicle approaches the stop.

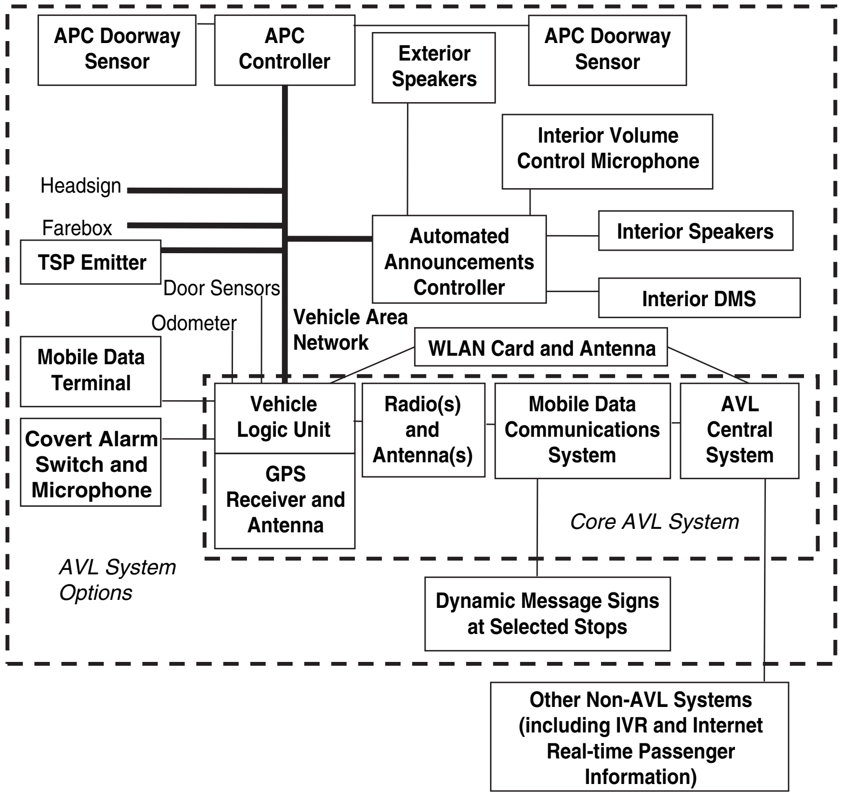

FIGURE 3 Core and optional AVL system components.

- Automatic data input to headsigns for display changes at the end of each trip (the headsigns are not treated as part of the AVL system).
- Automatic data exchange with fareboxes for providing trip segmentation and location data to the farebox and receiving alarms data from the farebox (the fareboxes are not treated as part of the AVL system).
- Onboard automatic passenger counting (APC) equipment to record the number of passengers boarding and alighting through each door at each stop.
- Ability to monitor vehicle mechanical status messages (i.e., from mechanical sensors or electronic control units for components such as engine, transmission, and air conditioning), record the data in the vehicle logic unit (VLU), and/or transmit the data to dispatch (the vehicle maintenance monitoring system is not treated as part of the AVL system).
- Covert alarm to send an emergency message to dispatch, sometimes with a covert microphone for audio monitoring from dispatch.
- Wireless local area network (WLAN) at vehicle storage areas to automate bulk data transfer between the central system and vehicle (e.g., to upload APC or maintenance data accumulated during a run or to download software updates for onboard devices).
- Use of schedule adherence and/or location data to develop real-time predictions for bus arrival times at stops, and providing these predicted arrival times and other service announcements to the public using various methods, including dynamic message signs (DMS) at selected stops, telephone-based customer information systems, and websites (these additional systems beyond DMS are not treated as part of the AVL system).
- Improving the effectiveness of transit signal priority (TSP) by making decisions on when to request and grant priority in part on the basis of real-time data on location, schedule adherence, and passenger loading (the TSP system is not treated as part of the AVL system).

AVL systems have also been increasingly adopted to support paratransit operations through the integration of bus AVL onboard systems and mobile data communications with paratransit operations management software that supports trip booking, scheduling, and dispatch.

A relatively recent development, with the availability of new options in higher speed mobile data communications and "thin client" computing technologies, has been the addition to AVL systems for effective remote access to AVL software from laptop computers mounted in non-revenue vehicles.

Mobile data communications is an essential element in the following areas:

- Between onboard components, most commonly using SAE J1708 communications;

- Wide area, using two-way radio systems or leased cellular data accounts; and
- Garage bulk data transfer, most commonly using IEEE 802.11x WLAN systems.

In recent AVL systems, integration with other agency systems (which are not treated as part of the AVL system, as defined in this synthesis) has been of increasing prominence including:

- Onboard
  - Video surveillance,
  - Farebox and smart card technology, and
  - Headsigns.
- Agency central systems
  - Fixed-route scheduling software,
  - Garage operations software,
  - Paratransit scheduling and dispatch software,
  - Traveler information systems (beyond DMS, which are treated as part of the AVL system),
  - Timekeeping and payroll,
  - Maintenance management,
  - Data warehouse software,
  - Geographic information systems, and
  - Systems operated by external agencies.

Emerging trends include:

- Agency-wide data warehousing and reporting tools.
- Broadband mobile data communications, and the new onboard applications that these will enable [e.g., real-time video transmission to dispatch and integration of the onboard system with the overall agency Wide Area Network (WAN)].
- Mobile access and location-based services for traveler information services.

Appendix C provides an overview of the systems engineering process that agencies have used successfully to deploy technology such as bus AVL systems. The systems engineering approach is effective for technology deployment in general, including bus AVL systems, and includes the following key steps:

- Needs and technology assessment;
- Projects definition and implementation plan;
- Procurement of individual technology deployment projects;
- Implementation management, including the transition of the technology into revenue service; and
- Evaluation of both the technology development process and of how the technology is being used.

CHAPTER TWO

REVIEW OF LITERATURE

This section briefly summarizes literature reviewed about developments in bus AVL systems over the past ten years. Researchers have prepared numerous academic papers on this topic; some of these papers explore potential enhancements to the computational methodologies used in AVL systems. Others consider aspects such as how agencies have been using bus AVL systems and what impacts these systems have had on agency operations, or review information that can be extracted using data accumulated by bus AVL systems. An overview of the information for a selection of this research follows.

- The U.S.DOT has sponsored research related to bus AVL systems through its Volpe Transportation Systems Center and various contractors, including:
  - The FTA recently published a comprehensive overview of the use of advanced technology in public transit (*2*), including bus AVL systems. This is the 2006 update of a series of such reports entitled *Advanced Public Transportation Systems: The State-of-the-Art.* This latest update provides details on the latest available technologies and how transit agencies are currently using them. It also emphasizes the importance of deploying technologies using a systems engineering approach and of using an agency-wide data management strategy.
  - A 2003 TCRP report focuses on the potential for transit agencies to enhance the archiving of data from bus AVL systems, in particular those systems offering both AVL and APC data, and the use of such archived data for management analysis. The emphasis is on the opportunities available to ensure that bus AVL systems serve as automated and comprehensive archived data collection systems, so that the potential of automated data analysis and decision support can be realized (*3,4*).
  - In 2000, the U.S.DOT Intelligent Transportation Systems (ITS) Joint Program Office (JPO) published one of a series of "Cross-Cutting Studies" to provide a general overview of transit AVL systems. This publication highlighted case studies in the successful use of AVL for transit agencies in Milwaukee, Wisconsin; Ann Arbor, Michigan; Seattle, Washington; Portland, Oregon; Montgomery County, Maryland (Washington, D.C. region); and Denver, Colorado (*5*). The average cost per bus for these six systems was reported as $15,500, which is consistent with the responses to Question 17 in the survey conducted for this synthesis (see chapter three) and the assessment of recent contract award values presented in chapter six. This report also summarizes an extensive list of benefits reported for these six AVL systems and by others, which are listed in detail in chapter six.
  - The ITS JPO Metropolitan ITS Infrastructure Deployment tracking program surveys on an ongoing basis the degree of ITS deployment of various types in 78 major metropolitan areas in the United States. The 2004 deployment survey results indicate that for the 220 transit agencies surveyed 23,425 fixed-route buses and 3,473 demand-responsive transit vehicles were equipped for AVL in 2004 (54% of the overall transit fleet at these agencies) (*6*). Similar deployment tracking research published in 2006 in the United Kingdom indicated that 16,132 fixed-routes buses in England, Scotland, and Wales were equipped for AVL by the end of 2005 (42% of the local bus fleet in Great Britain) (*7*). The breakdown of this fleet is 48% in London, 23% in other metropolitan transit authorities, and 29% in non-metropolitan transit authorities. Although the percentage of agencies that have deployed AVL (rather than the percentage of vehicles) would be of more interest, neither of these sources provides this information.
  - Research published in 1999 regarding a bus AVL system that went into operation for Denver's Regional Transportation District transit agency in 1996 examined the initial impacts on the work environment for dispatchers, supervisors, and operators. It was concluded that the amount of readily available and useful information increased, in particular for dispatchers, which increased both workload and effectiveness. This assessment also concluded that there was potential for the Regional Transportation District to use the data generated from this system to improve the efficiency of its schedules (*8,9*).
  - In 2003, a comprehensive evaluation was published for the Cape Cod Regional Transit Authority Advanced Public Transportation System. This was one of the earliest (completed in 2000) comprehensive implementations of a bus AVL system for a relatively small agency (at that time the Authority operated a fleet of 29 fixed-route buses and 69 demand-responsive vehicles) with a largely rural service area. This evaluation reports in detail on the benefits, costs,

and lessons learned through this effort. Overall, the evaluation suggests that even a small agency can benefit from bus AVL, with key lessons learned including (*10*):

- △ Recognizing that agencies will have to make infrastructure investments in communications and networking,
- △ Agencies should deploy new technologies incrementally so that the agency has time to adapt their operations, and
- △ Strong commitment from executive management is essential to ensure comprehensive and consistent use of the technology and data and to a long-term vision driving the effort.

– In research published in 2000, the Washington State Transportation Center of the University of Washington evaluated the BusView application, a pioneering effort making real-time fleet locations data for King County Metro in Seattle available to the general public by means of standard Internet browsers. This effort helped set the foundation for considerable innovation in recent years for the web-based delivery of customer information derived from bus AVL systems real-time data (*11*).

– In further research published in 2005, the Washington State Transportation Center evaluated the potential for using real-time fleet locations data for King County Metro to estimate current speeds for general traffic on specific road segments (i.e., using transit vehicles as "probes"). Some major routes are equipped with loop detectors that directly estimate general traffic speeds. A systems infrastructure was developed for using AVL data to estimate general traffic speeds (i.e., derived from transit vehicles speeds estimated using the AVL data) to provide supplementary information for additional important routes that were not equipped with loop detectors (*12*).

– In 2005, the ITS JPO published one of a series of "Cross-Cutting Studies" to highlight case studies of ITS incorporating an Archived Data User Service, including the data archiving capabilities of the King County Metro system (*13*).

– In 2006, FTA published a methodology for benefit-cost assessment of bus AVL system investments when used as an enabling technology for real-time customer information, with the assistance of a transit industry expert panel (*14*):

- △ Key features of the recommended methodology include using a Net Present Value benefit-cost calculation, employing full-cost accounting, and incorporating monetized, quantifiable, and qualitative benefit categories. The most challenging aspect reported was the difficulties associated with monetizing qualitative benefits.
- △ This methodology was validated to a limited extent using actual information for the investment decision to extend the existing TriMet AVL system to include the Transit Tracker system for real-time customer information by means of the Internet.
- △ The methodology concluded that depending on the assumptions regarding reduced wait times and reduced wait-time uncertainty, the number of annual transit trips with Transit Tracker information by means of the Internet that would be needed for positive net benefits ranges from approximately 200,000 to 900,000.

• The TriMet system was from the outset implemented to store and archive detailed operational databases. This enabled system evaluation and ongoing research from Portland State University and the University of Washington, some of which was sponsored by the Transportation Northwest Regional Center under the sponsorship of the U.S.DOT University Transportation Centers Grant Program. Diverse topics have been addressed including:

– Using archived data by the agency from the AVL system to:

- △ In 1999, evaluate the initial impacts of the AVL system, relative to pre-deployment levels, on service reliability measures such as on-time performance, headway variation, run time variation, and run times. The improved real-time information for dispatchers was expected to enhance the effectiveness of operational control, with the observed results of reducing running time by an average 1.45 min/trip and reducing average passenger waiting time at the stop by 0.11 min (*15*).
- △ In 2002, analyze the relationship between headway deviations and passenger loads (*16*).
- △ In 2002, assess schedule efficiency in terms of running and recovery times and operator-related running time variables (*17*).
- △ In 2002, evaluate the suitability of the APC data for use in National Transit Database (NTD) reporting, in conjunction with a suitable sampling plan. In part, based on this effort, TriMet reports that it has since secured approval from the NTD program to use its APC data for ridership reporting (*18*).
- △ In 2003, assess the impacts of implementing TSP on running times and on-time performance (*19*).
- △ In 2004, develop algorithms to help assess the determinants of bus dwell time at stops using archived APC data (*20*).

– Using data from the AVL system in real-time to:

- △ In 2001 and 2002, support a generalized real-time prediction algorithm for next arrival times at stops given current data on fleet vehicles positions and schedule, coupled with a statistical analysis of expected delay under abnormal conditions (e.g., lift bridge) (*21,22*).
- △ In 2000, support operational control strategies seeking to maintain headways (*23*).

– TriMet has made use of this research and its own ongoing internal efforts to make continuing improvements in how it uses the data from its AVL system (D. Crout, TriMet, Portland, Oregon, personal communication, June 12, 2007):

- △ The scheduling process now routinely uses AVL system data for more informed decisions on segment running and recovery times. For any given trip in the schedule, the process examines the set of data for the historical running times data experienced during the previous signup period.
- △ APC data are used not only to improve dwell time estimates for schedule development, but also to assess where stop spacing should be increased or decreased and where improved stop amenities are warranted.
- △ Recent efforts have focused on increasing the use of the AVL system data for dispatchers and supervisors. This has involved generating data of greatest interest to operations, such as summaries of operator speeds and schedule adherence, in some cases focusing on particular locations where an operational issue is suspected. Although TriMet operator work agreements preclude the direct use of AVL system data for operator disciplinary action, the data has been used by operations as an indicator of where direct investigation by supervisors is most warranted. By increasing the exposure to AVL system data for operations staff, it is hoped that they will independently identify additional uses for the data that are of greatest effectiveness for operations.

- The Partners for Advanced Transit and Highways program at the University of California reported extensively in 2002 on research related to bus AVL, with topics including:
  - Reviewing the early experiences of several transit agencies in the western United States with their bus AVL systems, with the results generally emphasizing (*24*):
    - △ Understanding the lessons learned regarding the importance of carefully planning how the system will be used and how it will fit with existing operations and infrastructure,
    - △ Working to build a positive attitude with staff toward the changes and ensuring that understanding and support for the system are vested throughout the entire staff, and
    - △ Understanding that the agency will need to have an ongoing commitment to effective operations and maintenance to gain the potential benefits from these systems.
  - Exploring algorithms to measure improvements in the efficiency of scheduling for demand-responsive transit service with AVL, with the focus on algorithms to measure the overall value from using real-time AVL data to support enroute diversion strategies considering both cost savings and passenger impacts (*25*).
- Other research includes:
  - In 2003, the Central Ohio Transit Authority (COTA) in Columbus, Ohio, evaluated the before-and-after effects of implementing a new bus AVL system on the efficiency and productivity of dispatchers (*26*). With the new AVL system there was a dramatic change in the amount of time spent each day by the dispatchers to create computer data logs of daily activity. Previously, dispatchers had written a manual log over the course of the day, which was transcribed into a computer log afterward. With the change to the ongoing automated collection of some data and the direct entry of other data into the AVL system by dispatchers, the overall effect was that nearly 3 h of daily work was avoided. COTA projected that over time this would allow the agency to accommodate an increase in fleet size by up to 10% with the current complement of dispatchers.
  - In 2004, Canadian researchers used a set of archived bus AVL and APC data from a route in Toronto to begin developing a predictive bus arrival and departure times model for decision support (*27*). The model uses a Kalman filter algorithm with recent data on AVL and APC data on route segment running times and passenger boarding volumes at stops to predict the running times and passenger arrival rates that will be experienced for upcoming trips. The decision support aspect of the tool would allow inputting operational scenarios (e.g., lane closures and special events) or control strategies (e.g., holding a bus at a time point to maintain headway), with the predictive algorithm being used to assess the expected effects on arrival and departure times along the route. This would allow the model to be used to preplan operational responses at dispatch to particular incident scenarios along the route by location and time of day.
  - As reported in 1999 research from the University of Southern California, bus AVL systems can be used to improve the efficiency of timed transfer operations at transit terminals (*28*). It is common to hold outgoing buses at such terminals for a few minutes if an incoming connecting bus is late, even though the incoming bus may also be delayed too much to arrive within the maximum hold time and may not have connecting passengers onboard. A role of the bus AVL system can be to inform central dispatch of predicted arrival times at the terminal as well as the routes to which passengers onboard inbound are connecting, allowing dispatch to determine when it is not necessary to hold the outbound bus.
  - Other research published in 2001 from University of Southern California examined how AVL can help improve the efficiency of demand-responsive paratransit dispatch operations. Real-time fleet location data can be incorporated into the dispatcher decision model (and thus into dispatcher training), in particular for making schedule adjustments to accommodate

same-day bookings and cancellations and vehicles running late (*29*).

– Research from the University of Delaware in 2004 evaluated the bus AVL system implemented by Delaware Authority for Regional Transit First State. A capital cost of approximately $7.6 million was attributed to the system, as well as an annual operating cost of $870,000. Benefits were assessed in detail and monetized where feasible. This analysis suggested that even considering only the portion of benefits that could be monetized, roughly $2.3 million in annual benefits could be reasonably attributed to the implementation of the system. On this basis, it was concluded that this implementation could be readily evaluated as having its benefits be expected to exceed its costs over a relatively brief period of operation (*30*).

CHAPTER THREE

SURVEY RESULTS

This chapter summarizes results from the synthesis survey.

Question 1. Agency information

Table 1 lists the agencies and individuals (with contact information) that provided survey responses, as well as the fixed-route and paratransit fleet size category reported by each agency. The 32 responses (from 31 agencies, with separate responses from King County Metro for fixed route and paratransit) are as intended predominantly from the United States, but represent various geographic regions:

- Canada and Europe (INT)—3 agencies reporting.
- Eastern United States (E)—10 agencies reporting.
- Midwestern United States (MW)—8 agencies reporting.
- Western United States (W)—11 agencies reporting.

Question 2. For each of the following modes, what fleet size (number of vehicles) does your agency either directly operate or subcontract?

Table 2 summarizes the distribution of the survey responses in terms of fleet size by mode. For the purposes of this report, the fixed-route and paratransit fleet sizes are most relevant:

- *Fixed route:* Roughly 20% of the responses to this question are from each of the following categories: 51–100 vehicles, 101–300 vehicles, and 301–600 vehicles. In addition, at least 5% of the responses are from each of the following categories: 11–50 vehicles, 601–900 vehicles, and 901–1,200 vehicles. Therefore, whereas most of the responses are from agencies where the fixed-route fleet size might be characterized as "medium–small" or "medium," there is also reasonable coverage in the survey for agencies in nearly every fixed-route fleet size category.
- *Paratransit:* Nearly 40% of the survey responses to this question are from agencies with fleet size in the category 11–50 vehicles, with about 20% of the responses from the categories 51–100 vehicles and 101–300 vehicles. There is also some coverage for all categories other than paratransit fleets that exceed 900 vehicles.

Question 3. Please specify for any "other" response in the previous question.

For this question no clarification was provided for the "other" responses.

Question 4. Which of the following describes the status of bus AVL system development at your agency?

Table 3 presents the distribution of responses by various categories for system development status at that agency. Approximately 84% of the responses to this question were from agencies with systems that are in revenue service. All respondents are at least planning a system implementation, as was intended with the selection of agencies invited to respond. The breakdown for the 84% of the responding agencies with a system in revenue service included about 56% that were in the process of being enhanced and about 28% that were not in the process of being enhanced. The predominance of in-service systems that were being enhanced appears to reflect that many agencies incrementally enhance their systems over time and that agencies were enhancing older bus AVL systems. These responses should not be taken as representative of the overall status of deployment throughout the public transit industry, because the primary purpose was to capture the experience of agencies that have already deployed a bus AVL system (or are in the process of developing one).

Question 5. Please indicate which of the following technologies, part of or integrated with a bus AVL system, your agency is implementing through the current enhancement effort.

Table 4 indicates the distribution of technologies that agencies will include in the enhanced AVL system, listed in order from the most commonly involved. Because the enhanced systems will typically involve multiple technologies, these percentages do not sum to 100%.

Current AVL system upgrades that agencies commonly reported (i.e., with at least 30% of the responses) that they were in the process of implementing include GPS, mobile data terminals (MDTs), automatic passenger counters (APCs), covert alarm, AVL software, next arrival predictions at stops, fixed-route scheduling software integration, covert microphone monitoring, and WLAN monitoring.

Question 6. Please indicate time periods when your agency implemented any of the following technologies, part of or integrated with a bus AVL system, and whether maintenance and support is currently provided under warranty.

Table 5 lists the time periods during which agencies implemented various technologies, listed in order by which had the

TABLE 1
SURVEY RESPONDENTS

Region	Name and Title of Respondent	Transit Agency Name	Fixed-Route Fleet Size Category	Paratransit Fleet Size Category
CAN/EUR	Steve Lassey, Program Manager, ITS	OC Transpo	901–1,200	51–100
CAN/EUR	Rajeev Roy, Manager, TMS	York Region Transit	101–300	11–50
CAN/EUR	Kimmo Sinisalo, IT Manager	YTV (Helsinki Metropolitan Area Council)	601–900	
E	Renee Mosura, Technology Manager	Beaver County (PA) Transit Authority	11–50	11–50
E	Leighton A. Williams	Broward County (FL) Transit	101–300	101–300
E	Elizabeth Presutti, Bus Operations Project Manager	Charlotte Area Transit System	301–600	51–100
E	Joe DeGray, Director of Transit Operations	Central NY Regional Transportation Authority	101–300	11–50
E	David Burnett, Deputy Chief of Transport	LYNX—Central Florida Regional Transportation Authority	101–300	11–50
E	David Carney, Division Chief BCC	Massachusetts Bay Transportation Authority	901–1,200	301–600
E	Pete Buckley, Program Manager	Montgomery County (MD) Ride On	301–600	
E	Eric Marx, Director of Planning and Operations	Potomac and Rappahannock Transportation Commission	51–100	11–50
E	Byron Comati, Director of Operational Analysis	Southeastern Pennsylvania Transportation Authority	901–1,200	301–600
E	Laurie Barrett, Director of Bus Operations	Triangle Transit Authority	51–100	1–10
MW	Rick Cain	Central Oklahoma Transportation and Parking Authority	51–100	11–50
MW	John C. Lancaster, Senior Planner	Memphis (TN) Area Transit Authority	101–300	51–100
MW	Gregory Lind, Manager, Radio Communications	Metro/Southwest Ohio Regional Transit Authority	301–600	51–100
MW	Steve McLaird, Assistant Manager TC—Operations	Metro Transit—Minneapolis	901–1,200	
MW	John Braband	PACE (IL)	601–900	601–900
MW	Jeff Nelson	Rock Island County (IL) Metro Transit District	51–100	11–50

(continued on next page)

TABLE 1 (*Continued*)

Region	Name and Title of Respondent	Transit Agency Name	Fixed-Route Fleet Size Category	Paratransit Fleet Size Category
MW	John Cullen, Technical Program Manager	Transit Authority of River City (KY)	101–300	51–100
MW	Robert C. Johnson, Transit Director	Waukesha Metro Transit (WI)	51–100	1–10
W	John Rudniski, Director of Maintenance	AC Transit (CA)	601–900	11–50
W	Kevin Mehta, Consultant	Antelope Valley (CA) Transit Authority	11–50	11–50
W	Mike Nevarez, Operations Manager	City of Phoenix—Public Transit Department	301–600	101–300
W	Michael Harbour, General Manager	Intercity Transit	51–100	11–50
W	Janey Elliott, Transportation Planner	King County Metro—Access Transportation		101–300
W	Dan Overgaard, IT Supervisor	King County Metro Transit	1,201+	
W	Barbara Duffy, General Manager	Livermore Amador Valley (CA) Transit Authority	51–100	11–50
W	Dennis Elefante, Manager, Maintenance Support Services	Orange County Transportation Authority	601–900	101–300
W	Dan Trent, Manager of Transportation	San Diego Metropolitan Transit System	101–300	
W	Frank Burton, Manager Operations Technology	San Mateo County Transit District	301–600	51–100
W	Mike Hursh, Deputy Director, Maintenance	Santa Clara Valley Transportation Authority	301–600	101–300

CAN/EUR = Canada and Europe; E = East; MW = Midwest; W = West.

TABLE 2
FLEET SIZE BY MODE

Mode	1–10	11–50	51–100	101–300	301–600	601–900	901–1,200	1,201+
Fixed-Route Bus	0.0%	6.5%	22.6%	22.6%	19.4%	12.9%	12.9%	3.2%
Paratransit	7.1%	39.3%	21.4%	21.4%	7.1%	3.6%	0.0%	0.0%
Heavy Rail/Subway	50.0%	0.0%	0.0%	0.0%	50.0%	0.0%	0.0%	0.0%
Light Rail/Streetcar	37.5%	25.0%	12.5%	25.0%	0.0%	0.0%	0.0%	0.0%
Bus Rapid Transit	14.3%	57.1%	28.6%	0.0%	0.0%	0.0%	0.0%	0.0%
Commuter Rail	16.7%	33.3%	16.7%	0.0%	33.3%	0.0%	0.0%	0.0%
Ferry	66.7%	33.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other	25.0%	25.0%	25.0%	25.0%	0.0%	0.0%	0.0%	0.0%

TABLE 3
SYSTEM DEVELOPMENT STATUS

Status	%
In revenue service and is being currently enhanced	56.3
In revenue service and is not being currently enhanced	28.1
Being implemented	6.3
Being procured	6.3
Being planned	3.1
No current interest	0.0

most responses for deployment after 2003. The technologies most commonly (i.e., with at least 20% of responses) reported as being implemented after 2003 were:

- GPS
- APC
- Paratransit scheduling/dispatch software integration
- MDTs
- AVL software
- Supervisor mobile access to AVL software
- Next arrival predictions at stops

TABLE 4
TECHNOLOGIES INVOLVED IN CURRENT SYSTEM ENHANCEMENTS

Technologies	%
GPS Receivers	43.8
Operator Display/Keypad	40.6
APC	37.5
Covert Alarm Monitoring	37.5
AVL Software for Fixed-Route Operations	37.5
Next Arrival Predictions via Signs at Stops	37.5
Fixed-Route Scheduling Software Integration	34.4
Covert Microphone Monitoring	31.3
WLAN Integration	31.3
Onboard Computer	28.1
Interior Next Stop Announcements	28.1
Next Arrival Predictions via Website	28.1
Odometer Integration	25.0
Headsign Integration	25.0
Mobile Radio Integration	25.0
Paratransit Scheduling/Dispatch Software Integration	25.0
Next Arrival Predictions via Automated Telephone System	25.0
Transit Signal Priority	21.9
Next Arrival Predictions via Website, for Access with Mobile Personal Devices	21.9
Farebox Integration	18.8
Mobile Radio System Enhancements	18.8
Cellular Data Service Integration	18.8
Supervisor Mobile Access to AVL Software	18.8
Digital Video Recorder Integration	15.6
Data Warehouse Integration	15.6
Exterior Announcements at Stops	12.5
Display/Keypad and Location Monitoring for Non-Revenue Vehicles	9.4
Next Arrival Predictions via E-Mail Subscription	9.4
Drivetrain Monitoring	6.3
Other	6.3
Heading Sensor	3.1

TABLE 5
TIME PERIODS WHEN VARIOUS TECHNOLOGIES WERE IMPLEMENTED

Technologies	1997 or Earlier	1998–2000	2001–2003	2004 or Later	Currently Under Warranty?
GPS Receivers	9.4%	15.6%	25.0%	25.0%	31.3%
APCs	6.3%	9.4%	15.6%	25.0%	18.8%
Paratransit Scheduling/Dispatch Software Integration	0.0%	3.1%	12.5%	25.0%	9.4%
Operator Display/Keypad	9.4%	15.6%	18.8%	21.9%	25.0%
AVL Software for Fixed-Route Operations	15.6%	15.6%	15.6%	21.9%	18.8%
Supervisor Mobile Access to AVL Software	0.0%	3.1%	6.3%	21.9%	9.4%
Next Arrival Predictions via Signs at Stops	0.0%	9.4%	18.8%	21.9%	18.8%
Next Arrival Predictions or Paratransit Trip Information via Automated Telephone System	0.0%	0.0%	0.0%	21.9%	6.3%
Interior Next Stop Announcements	3.1%	9.4%	9.4%	18.8%	12.5%
Covert Alarm Monitoring	15.6%	12.5%	25.0%	18.8%	21.9%
Covert Microphone Monitoring	12.5%	12.5%	15.6%	18.8%	18.8%
WLAN Communications	0.0%	9.4%	12.5%	18.8%	6.3%
Fixed-Route Scheduling Software Integration	12.5%	9.4%	18.8%	18.8%	15.6%
Data Management System Integration	3.1%	12.5%	9.4%	18.8%	9.4%
Central System Hardware/Software Upgrades	3.1%	15.6%	18.8%	18.8%	6.3%
Odometer Integration	3.1%	15.6%	18.8%	15.6%	18.8%
Onboard Computer	6.3%	12.5%	18.8%	15.6%	21.9%
Headsign Integration	3.1%	6.3%	6.3%	15.6%	9.4%
Cellular Data Service Communications	0.0%	0.0%	3.1%	15.6%	6.3%
Dispatch Center Workstation Furniture	9.4%	21.9%	18.8%	15.6%	15.6%
Transit Signal Priority	0.0%	3.1%	6.3%	12.5%	6.3%
Integrated Digital Video Recorder	0.0%	3.1%	3.1%	12.5%	0.0%
Next Arrival Predictions or Paratransit Trip Information via Website	0.0%	3.1%	3.1%	12.5%	3.1%
Exterior Announcements at Stops	3.1%	9.4%	9.4%	9.4%	6.3%
Farebox Integration	0.0%	3.1%	9.4%	9.4%	18.8%
Mobile Radio Voice Communications Integration	9.4%	12.5%	25.0%	9.4%	15.6%
Mobile Radio Data Communications	9.4%	12.5%	25.0%	9.4%	21.9%
Mobile Radio System Enhancements	3.1%	0.0%	6.3%	6.3%	3.1%
Display/Keypad and Location Monitoring for Non-Revenue Vehicles	3.1%	6.3%	9.4%	6.3%	6.3%
Next Arrival Predictions or Paratransit Trip Information via Website, for Access with Mobile Personal Devices	0.0%	0.0%	6.3%	6.3%	3.1%
Next Arrival Predictions or Paratransit Trip Information via E-Mail Subscription	0.0%	0.0%	0.0%	6.3%	0.0%
Heading Sensor	0.0%	0.0%	3.1%	3.1%	3.1%
Drivetrain Monitoring	0.0%	0.0%	6.3%	3.1%	3.1%
Other	0.0%	3.1%	0.0%	3.1%	0.0%
Transponder or Transponder Receiver (Si gnpost" Technology)	18.8%	0.0%	0.0%	0.0%	0.0%

- Passenger information by means of an interactive voice response (IVR) telephone information system.

Another interesting category are those technologies that might be referred to as "recently established," in this case defined as technologies agencies responded that they deployed after 2003 that were at least 10% higher than those from 2001 to 2003. These technologies include:

- Paratransit scheduling and dispatch software integration,
- Supervisor mobile access to AVL software,
- Passenger information by means of IVR, and
- Cellular data service communications.

Table 6 provides a breakdown of the specific subsystems reported as implemented through the survey.

Question 7. Please specify for any "other" response in the previous question.

For this question there were no "other" responses.

Question 8. Please indicate for any of the following technologies, part of or integrated with a bus AVL system, the portion of the fixed-route bus fleet your agency has equipped.

Table 7 shows the percentage of the overall fixed-route fleet equipped with various technologies, listed in decreasing order for the percentage of responses involving the technology deployed with 81% to 100% of the fixed-route fleet. The technologies for which less than 50% of the responses indicated this full (or nearly so) level of deployment are transit signal priority, APCs, and integrated digital video recorders.

Question 9. Please specify for any "other" response in the previous question.

For this question there were no "other" responses.

Question 10. Please indicate for any of the following technologies, part of or integrated with a bus AVL system, the portion of the paratransit bus fleet your agency has equipped.

Table 8 shows for various technologies the percentage of the overall paratransit fleet equipped, listed in decreasing order for the percentage of responses involving the technology deployed with 81% to 100% of the paratransit fleet. The technologies for which less than 50% of the responses indicated this full (or nearly so) level of deployment are heading sensors, farebox integration, and integrated digital video recorders.

Question 11. Please specify for any "other" response in the previous question.

For this question there were no "other" responses.

Question 12. Please indicate the approximate service area (in square miles) supported by your bus AVL system (fixed-route).

The average response was 603 square miles.

Question 13. Please indicate the approximate service area (in square miles) supported by your bus AVL system (paratransit).

The average response was 387 square miles.

Question 14. Please indicate the equipment suppliers and integrators for the technologies, part of or integrated with a bus AVL system that your agency has implemented.

The responses to this question are from systems that are reasonably representative of the range of established bus AVL systems integrators, although some of the current systems integrators are not represented in the responses. Currently active bus AVL system integrators represented in the responses are INIT, Mentor Engineering, Nextbus, Orbital Sciences, and Siemens VDO.

The following are the specific responses to this question:

- Trapeze Ops is a time and attendance system that is currently interfaced with the computer-aided dispatch (CAD) system.
- The fixed-route system was provided by Harris Corp., with several subcontractors. They are no longer in the transit business.
- Orbital TMS, Integrator; APC, IRIS; on board announcements, Digital Recorders; radio, Motorola; GPS—Garmin.
- Orbital & M/A-COM digital RF for fixed-route and Trapeze/cellular link for paratransit. Fixed-route also includes integration to Luminator signs, digital recorder announcements, and GFI farebox.
- AESF Communications (out of business), Motorola radios.
- MDTs, AVL, and odometer readers from Greyhawk Technologies, Inc. Scheduling and dispatch software from Trapeze Group, Inc. Some applications developed by contracted call center Information Systems staff.
- Radio Satellite Integrators and GFI.
- Siemens.
- Siemens VDO.
- INIT Innovations in Transportation Inc., IBI Group.
- Siemens Trapeze.
- Orbital TMS, Motorola.
- Orbital TMS, Giro, Trapeze.
- Thoreb (Sweden), IVS (Tampere, Finland), Buscom (Oulu, Finland).
- Orbital, ACS.
- Orbital Sciences, Motorola.
- Trapeze, Mentor Engineering.

TABLE 6
REPORTED SUBSYSTEMS BY AGENCY

Transit Agency Name	GPS Receivers	Operator Display/Keypad	Interior Next Stop Announcements	APC	Covert Alarm Monitoring	Transit Signal Priority	Drivetrain Monitoring	Headsign Integration	Farebox Integration	Cellular Data Service Communications	WLAN Communications	CAD/AVL Software for Fixed-Route	Fixed-Route Scheduling Software Integration	Paratransit Scheduling/Dispatch Software	Supervisor Mobile Access to CAD/AVL Software	Next Arrival Predictions via DMS at Stops	Passenger Information via IVR	Passenger Information via Website
AC Transit	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
Antelope Valley Transit Authority	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	
Beaver County Transit Authority	X	X		X								X				X		
Broward County Transit	X	X			X							X	X					
Central Oklahoma Transportation and Parking Authority	X															X		
City of Phoenix—Public Transit Department	X	X	X	X	X					X		X	X	X		X		
Central New York Regional Transportation Authority (Centro)	X			X	X							X	X					
King County Metro—Access Transportation	X	X			X									X	X		X	
King County Metro Transit		X		X	X	X					X	X	X			X		X
Livermore Amador Valley Transit Authority	X	X	X	X	X		X	X			X	X	X	X		X		
Metro/Southwest Ohio Regional Transit Authority	X	X	X	X	X						X	X	X	X				
Metro Transit—Minneapolis	X	X		X	X				X		X	X	X		X	X	X	X
Montgomery County Ride On	X	X	X									X	X			X		
OC Transpo	X	X		X	X	X				X	X	X	X	X				
Orange County Transportation Authority	X	X	X	X	X			X	X	X	X	X	X	X			X	
PACE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Potomac and Rappahannock Transportation Commission (PRTC)	X	X			X									X				
Rock Island County Metro Transit District	X		X	X	X			X				X	X	X		X		
San Diego Metropolitan Transit System	X	X		X	X			X	X			X	X		X			

(continued on next page)

TABLE 6 (*Continued*)

Transit Agency Name	GPS Receivers	Operator Display/Keypad	Interior Next Stop Announcements	APC	Covert Alarm Monitoring	Transit Signal Priority	Drivetrain Monitoring	Headsign Integration	Farebox Integration	Cellular Data Service Communications	WLAN Communications	CAD/AVL Software for Fixed-Route	Fixed-Route Scheduling Software Integration	Paratransit Scheduling/Dispatch Software	Supervisor Mobile Access to CAD/AVL Software	Next Arrival Predictions via DMS at Stops	Passenger Information via IVR	Passenger Information via Website
San Mateo County Transit District	X	X	X	X	X	X					X	X	X	X	X	X		
Santa Clara Valley Transportation Authority	X		X	X	X			X				X		X				
Southeastern Pennsylvania Transportation Authority	X	X	X	X	X	X					X	X	X		X	X		
Transit Authority of River City	X													X				
Triangle Transit Authority	X	X										X						
Waukesha Metro Transit	X	X			X				X			X	X			X		
York Region Transit	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X
YTV (Helsinki Metropolitan Area Council)	X		X			X										X		X

- INIT, Twin Vision Signs.
- Orbital Sciences Corp., GFI, Luminator, Twin Vision, Hastus.
- Bell Canada, X-Wave, Mobile Knowledge, Trapeze Software, Giro Inc.
- NextBus.
- Siemens TransitMaster, Giro Hastus, Digital Data Voice, Hewlett Packard, Antenna Specialists, Motorola, MA/Comm, Cisco, Cubic, Red Pine, Proxim.
- Harris Corporation (FleetLynx AVL) Motorola 800 MHz trunked radio and data system. Luminator signs and annunciators, Urban Transportation Associates (APCs) Trapeze Schedule/Paratransit suites, Safety Vision on-board digital cameras, and GFI fareboxes. All are stand-alone systems.
- Siemens.
- We have two separate systems:
  - Was developed at Potomac and Rappahannock Transportation Commission (PRTC) for flex-route service (defined here as paratransit) using Trapeze for scheduling and Greyhawk for vehicle equipment.
  - Fixed-route buses use Nextel phones equipped with GPS and Air-Trak which hosts the web service with tracking information.
- Motorola, Orbital, Giro.
- Orbital Sciences, Motorola, Teletronics.

Question 15. At what time interval (in seconds) are AVL location reports received from any particular vehicle in your bus AVL system (for example, many systems poll the fleet such that the location is updated for each vehicle every 60–120 seconds)?

The average response was 95 s, with the achievable polling rate depending on the available capacity in the mobile data communications system and the efficiency of the AVL system polling protocol, relative to the fleet size. The shortest reported polling interval was 15 s, whereas the longest reporting polling interval was 300 s. The most commonly reported polling interval was 120 s, with 11 responses. Although some systems use a relatively lengthy regular polling interval, this is typically supplemented by some exception-based vehicle reports (e.g., if the bus schedule deviation passes a set threshold).

Question 16. Which of the following best describes how your agency deployed the bus AVL system?

Table 9 summarizes responses to this question on the approaches to staging the system procurement and rollout.

TABLE 7
PORTION OF FIXED-ROUTE FLEET EQUIPPED WITH VARIOUS TECHNOLOGIES

Technologies	1%–20%	21%–40%	41%–60%	61%–80%	81%–100%
Heading Sensor	0.0	0.0	0.0	0.0	100.0
Drivetrain Monitoring	0.0	0.0	0.0	0.0	100.0
Other	0.0	0.0	0.0	0.0	100.0
Mobile Radio Voice Communications Integration	0.0	0.0	5.9	0.0	94.1
Mobile Radio Data Communications	5.6	0.0	5.6	0.0	88.9
Onboard Computer	0.0	5.9	5.9	0.0	88.2
Operator Display/Keypad	0.0	9.5	4.8	0.0	85.7
Transponder or Transponder Receiver (“signpost” technology)	16.7	0.0	0.0	0.0	83.3
Covert Microphone Monitoring	0.0	5.6	5.6	5.6	83.3
GPS Receivers	4.2	8.3	8.3	0.0	79.2
Covert Alarm Monitoring	0.0	8.7	8.7	4.3	78.3
Exterior Announcements at Stops	0.0	10.0	10.0	10.0	70.0
Odometer Integration	5.6	11.1	5.6	11.1	66.7
Farebox Integration	0.0	11.1	22.2	0.0	66.7
Interior Next Stop Announcements	7.7	7.7	7.7	15.4	61.5
WLAN Communications	38.5	7.7	0.0	0.0	53.8
Headsign Integration	0.0	20.0	20.0	10.0	50.0
Cellular Data Service Communications	25.0	12.5	0.0	12.5	50.0
Transit Signal Priority	62.5	12.5	0.0	0.0	25.0
Integrated Digital Video Recorder	42.9	28.6	0.0	14.3	14.3
APCs	44.4	22.2	16.7	5.6	11.1

TABLE 8
PORTION OF PARATRANSIT FLEET EQUIPPED WITH VARIOUS TECHNOLOGIES

Technologies	1%–20%	21%–40%	41%–60%	61%–80%	81%–100%
Mobile Radio Data Communications	12.5	0.0	0.0	0.0	87.5
Mobile Radio Voice Communications Integration	16.7	0.0	0.0	0.0	83.3
GPS Receivers	13.3	0.0	0.0	6.7	80.0
Operator Display/Keypad	13.3	0.0	0.0	6.7	80.0
Cellular Data Service Communications	20.0	0.0	0.0	0.0	80.0
Onboard Computer	18.2	0.0	0.0	9.1	72.7
Covert Alarm Monitoring	10.0	0.0	0.0	20.0	70.0
Covert Microphone Monitoring	16.7	0.0	0.0	16.7	66.7
Odometer Integration	25.0	0.0	0.0	25.0	50.0
Drivetrain Monitoring	50.0	0.0	0.0	0.0	50.0
WLAN Communications	50.0	0.0	0.0	0.0	50.0
Other	50.0	0.0	0.0	0.0	50.0
Heading Sensor	66.7	0.0	0.0	0.0	33.3
Farebox Integration	25.0	0.0	25.0	25.0	25.0
Integrated Digital Video Recorder	100.0	0.0	0.0	0.0	0.0

TABLE 9
PROCUREMENT STAGING APPROACH

Stage	%
With a single procurement and a single deployment stage	25.9
With a single procurement and multiple rollout stages	51.9
With multiple procurements	22.2

The question asked whether agencies deployed the system with a single or multiple procurements, and whether they deployed a single procurement using multiple rollout stages. The most common staging approach (at more than 50% of the responses to this question) was for a single procurement with multiple deployment stages.

This is consistent with the deployment of complex yet integrated systems. The overall integrated nature of these systems makes it advantageous to use a single procurement, contracting with a single systems integrator that can serve as the sole point of accountability for system performance. The complexity and number of different subsystems leads to the common use of multiple deployment stages within the overall deployment contract. This allows the agency to initially bring into operation a core functionality system that staff can adapt to using before additional subsystems are added.

Question 17. Please indicate the cumulative capital cost for your bus AVL system, on a per equipped vehicle basis (please attempt to include the full range of capital costs associated with the system, including the costs for vehicles and central systems, but exclude any capital costs for mobile radio system enhancements).

Table 10 summarizes the responses on system capital costs, expressed on a per vehicle basis given the fleet size. Costs were excluded for mobile radio system enhancements, because some agencies include this in the overall AVL system cost whereas others do not (mobile radio system costs are addressed in Question 18). The most common response was about 33% for the range $10,001 to $20,000; with about 82% of the responses for less than $30,000 per vehicle. With the responses for smaller agencies, the cost per vehicle is biased upward because the central system cost is spread across a smaller number of vehicles. As discussed in chapter six, recent contract awards suggest $10,000 to $20,000 per vehicle as a general rule of thumb for capital costs. It is also worth noting that roughly 11% of the responses indicated a per vehicle capital cost of $90,000 or more. This represents an unlikely circumstance and may involve a misunderstanding of the question.

Question 18. Please indicate any capital cost for mobile radio system enhancements needed to support your bus AVL system, on a per equipped vehicle basis.

Table 11 summarizes the responses on system capital costs for mobile communications system enhancements needed to support the bus AVL system, expressed on a per vehicle basis given the fleet size. The most common response from about 38% of the respondents was $1,000 or less. This cost varies largely with the service area and fleet size, but is roughly proportional to the fleet size.

The intent was that this cost be limited to the enhancements that are only needed to support the AVL system implementation (e.g., for mobile data communications or for control of access to voice communications by means of the AVL system), as opposed to enhancements that would be needed regardless of AVL such as for voice communications alone. However, it is possible that the actual scope of communications-related costs varies in the responses based on the interpretation of "needed to support your bus AVL system."

TABLE 10
SYSTEM NON-COMMUNICATIONS CAPITAL COSTS ON A PER VEHICLE BASIS

Capital Cost	%
$10,000 or less	22.2
$10,001–$20,000	33.3
$20,001–$30,000	25.9
$30,001–$40,000	3.7
$40,001–$50,000	3.7
$50,001–$60,000	0.0
$60,001–$70,000	0.0
$70,001–$80,000	0.0
$80,001–$90,000	0.0
$90,001–$100,000	7.4
More than $100,000	3.7

TABLE 11
SYSTEM COMMUNICATIONS CAPITAL COSTS ON A PER VEHICLE BASIS

Capital Cost	%
$1,000 or less	38.1
$1,001–$2,000	19.0
$2,001–$3,000	9.5
$3,001–$4,000	9.5
$4,001–$5,000	9.5
$5,001–$6,000	0.0
$6,001–$7,000	0.0
$7,001–$8,000	4.8
$8,001–$9,000	9.5
$9,001–$10,000	0.0
More than $10,000	0.0

Question 19. Please indicate the approximate breakdown for the sources of the capital costs for your bus AVL system, on a percentage basis.

Table 12 examines responses to the question on the sources of the capital funds used for the AVL system, listing the average percentage contribution to the total capital funding from various sources. As discussed in chapter six, capital costs are for initial implementation of the system.

The most common source was reported as federal funding at about 55%, divided between federal grants explicitly targeted for Intelligent Transportation System (ITS) deployment (19%) and other federal funding (e.g., formula grants) (36%). About 30% was reported as coming from local funds, with 10% from agency revenues and 10% from other local sources (e.g., municipal tax base).

Question 20. Please indicate the approximate breakdown for the sources of the operating costs for your bus AVL system, on a percentage basis.

Table 13 examines responses to the question on the sources of the operating funds used for the AVL system, listing the average percentage contribution to the total operating funding from various sources. As discussed in chapter six, operation costs are those attributable to the ongoing use and maintenance of the system. The most common source was reported as local funding at about 70%, with about 36% from agency revenues and another 34% from other local sources.

Question 21. Please indicate the current operating cost that you feel is directly attributable to your bus AVL system, on a per equipped vehicle basis (please attempt to include the full range of operating costs, including maintenance, incremental staffing, and training/retraining).

Table 14 summarizes the responses on system operating costs for the bus AVL system, expressed on a per vehicle basis given the fleet size. About 77% of the responses were in the range of $2,000 or less.

TABLE 12
SOURCES OF CAPITAL COSTS FUNDING

Source	Average (%)
Federal ITS Grant	19.4
Other Federal Funding	35.6
State Funding	15.3
Local Funding	19.5
Agency Revenues	10.3

ITS = Intelligent Transportation System.

TABLE 13
SOURCES OF OPERATING COSTS FUNDING

Source	Average (%)
Federal ITS Grant	3.7
Other Federal Funding	12.8
State Funding	13.6
Local Funding	33.7
Agency Revenues	36.3

Question 22. Please indicate any additional comments or detail about the composition and/or staged deployment of your bus AVL system.

Agencies provided many interesting comments about how they specifically approached the deployment of their bus AVL system. A frequent comment was the need to stage the deployment of the fixed-route fleet owing to the large number of vehicles involved. Examples included using an initial pilot-level deployment before proceeding to rollout across the entire fleet, and staging the full fleet rollout incrementally across each garage.

With many agencies now offering, implementing, or planning bus rapid transit (BRT) services that are marketed as providing superior service, the AVL system staging sometimes involves using the BRT service as an initial focus. Examples of AVL systems being deployed in the initial stage for a BRT service only, with subsequent rollout intended system-wide, are the Viva BRT service in York Region Transit (near Toronto, Ontario) and the iExpress BRT service for Grand River Transit (Kitchener, Ontario). There are other examples showing that even though the AVL system was deployed throughout the fleet in the initial stage, the initial stage of real-time passenger information at stops was focused on the BRT service [e.g., the Metropolitan Area

TABLE 14
SYSTEM OPERATING COSTS ON A PER VEHICLE BASIS

Cost	%
$1,000 or less	38.5
$1,001–$2,000	38.5
$2,001–$3,000	7.7
$3,001–$4,000	3.8
$4,001–$5,000	7.7
$5,001–$6,000	0.0
$6,001–$7,000	3.8
$7,001–$8,000	0.0
$8,001–$9,000	0.0
$9,001–$10,000	0.0
More than $10,000	0.0

eXpress (MAX) BRT of the Kansas City Area Transportation Authority (KCATA) in Kansas City, Missouri].

The following notes the specific responses to this question:

- Fixed route was a single procurement with phased implementation; paratransit was a single procurement with single implementation.
- Costs include extended warranty, software maintenance, and one dedicated full-time equivalent support position. Some maintenance was performed by contracted service operators as part of fixed fee.
- The answers given relate to current piecemeal systems on average; planned complete system (implementation 2009–2010) should change almost everything.
- Phase 1—Limited pilot on 20 buses for proof of concept; Phase 2—Complete deployment on 1,100 vehicles.
- We deployed a test fleet to system test. Owing to the number of vehicles and installation time, we deployed equipment on a garage-by-garage schedule. We have five service garages and one overhaul base.
- Turn-key project; Harris was prime.
- Since we really have two completely different systems the information I am providing is going to be of limited value because in some cases I have averaged items (e.g., costs) and in others broken them out by service type.
- Ours was a multi-agency, multi-jurisdictional procurement. Deployed RF network, then deployed agencies incrementally.
- System was first implemented in 1996 on half of our fleet; two years later the second half was bought on. We are now in the process of upgrading to Orbital XP that will be a three-phase project starting in July 2007.

Question 23. Can we contact you for press releases issued about your bus AVL system for use in this synthesis project?

Nineteen agencies indicated they could be contacted for this information:

- AC Transit
- Antelope Valley Transit Authority
- Beaver County Transit Authority
- Broward County Transit
- City of Phoenix—Public Transit Department
- CNY Centro
- King County Metro Transit
- Metro Transit—Minneapolis
- Metro/Southwest Ohio Regional Transit Authority
- Montgomery County Ride On
- OC Transpo
- Orange County Transportation Authority
- PRTC
- Rock Island County Metro Transit District
- San Mateo County Transit District
- Santa Clara Valley Transportation Authority
- Southeastern Pennsylvania Transportation Authority
- Transit Authority of River City
- York Region Transit.

Question 24. Can we contact you for evaluation results about your bus AVL system performance and how you are using the system for use in this synthesis project?

Twenty-five agencies indicated they could be contacted for this information:

- AC Transit
- Antelope Valley Transit Authority
- Beaver County Transit Authority
- Broward County Transit
- Central OK Transportation and Parking Authority
- City of Phoenix—Public Transit Department
- CNY Centro
- King County Metro Transit
- Metro Transit—Minneapolis
- Metro/Southwest Ohio Regional Transit Authority
- Montgomery County Ride On
- OC Transpo
- Orange County Transportation Authority
- PACE
- PRTC
- Rock Island County Metro Transit District
- San Diego Metropolitan Transit System
- San Mateo County Transit District
- Santa Clara Valley Transportation Authority
- Southeastern Pennsylvania Transportation Authority
- Transit Authority of River City
- Triangle Transit Authority
- Waukesha Metro Transit
- York Region Transit
- YTV (Helsinki Metropolitan Area Council).

Question 25. Can we contact you for the results for any surveys and/or focus groups conducted to gather customer feedback on your bus AVL system and how you are using it for use in this synthesis project?

Twenty-two agencies indicated they could be contacted for this information:

- AC Transit
- Antelope Valley Transit Authority
- Beaver County Transit Authority
- Broward County Transit
- City of Phoenix—Public Transit Department
- CNY Centro

- King County Metro Transit
- Metro Transit—Minneapolis
- Metro/Southwest Ohio Regional Transit Authority
- Montgomery County Ride On
- OC Transpo
- Orange County Transportation Authority
- PRTC
- San Diego Metropolitan Transit System
- San Mateo County Transit District
- Santa Clara Valley Transportation Authority
- Southeastern Pennsylvania Transportation Authority
- Transit Authority of River City
- Triangle Transit Authority
- Waukesha Metro Transit
- York Region Transit
- YTV (Helsinki Metropolitan Area Council).

Question 26. What bus AVL system technologies, and ways of using these technologies, have been most effective with your agency (and why)?

Technologies commonly cited as effective include those that collect data on location and schedule adherence, both for operational control and service restoration, as well as those technologies that feed data back to planning for creating the most realistic schedules. Other effective uses mentioned were those that helped validate or disallow customer complaints, and supported next arrival predictions at stops. One response also noted how they have been able to use AVL system data to successfully discipline operators to discourage early timepoint departures, while largely avoiding operator grievances because the data supported the disciplinary actions.

One interesting response noted that the comprehensive on-time performance data available revealed that system on-time performance was not as good as they had thought. With information about actual on-time performance, agencies can take steps to improve on-time performance by establishing more realistic schedules and addressing any underlying operational issues. However, it may be a good idea for a system implementing a bus AVL system to prepare user expectations for this potential scenario.

The following specific responses were provided for this question:

- Use of AVL data for scheduling and planning; use of AVL data for researching customer service issues; real-time bus arrival information for customers through the web.
- The District is using a system provided by Orbital Sciences TMS. We use the system for field control and management of fixed-route, paratransit, and supervisory support vehicles. The system provides us with, in addition to many other things, the ability to track schedule performance in near real time. It also collects the data historically. Finally, the system is used to "stamp" passenger count data at bus stops. The use of real-time AVL has allowed our dispatchers to become very effective at field management with an emphasis on service restoration. The ability to see where a vehicle is disabled etc., and locate the nearest vehicle by means of a graphical interface has enabled a much quicker response to problems. In addition, the historical data collection is being used extensively by scheduling and planning to more effectively plan service. Ridership tracked by location is another effective use of the system and has allowed some reallocation of resources to meet demand.
- Route schedule adherence and planning for fixed-route, advance scheduling, and near real-time performance data for paratransit.
- GPS used for on-time performance, scheduling, and planning.
- MDTs with AVL have been extremely useful in our paratransit operation. Drivers love having on-board mapping, route-finding, access to the Washington State Department of Transportation traffic map and the ability to respond to dispatch when they are not driving or assisting passengers. Dispatch and administrative staff use AVL data in many ways, both day of service and after the fact (documenting or disputing no-shows or late pull-outs, for example).
- Verifying complaints and monitoring on-time performance.
- On-time performance data verifies (or disallows) passenger complaints.
- AVL and next stop announcements.
- Traveler information systems, transit signal priority (TSP), and central monitoring.
- Integrating the headsigns with the AVL, APCs, and GPS monitoring.
- GPS-based AVL system is used for performance monitoring, safety, and security purposes. Additional data are used for service planning, scheduling, service quality, service monitoring, customer service, and passenger information.
- Emergency alarm, route schedule adherence, vehicle location display on map, schedule display, voice and data communication capability, greater efficiency in daily operations.
- Dynamic passenger information system(s), automobile traffic priority—preempt with consideration for passenger load factor and schedule status (early, late).
- Route schedule adherence (RSA)—Comparison of actual route time/place with schedule; make appropriate changes to schedules.
- Paratransit operations have been improved: performance monitoring, real-time customer service information for customer service representatives, incident investigation.

- Wayside signage—Positive customer response real-time data—accurate planning passenger counters—accurate planning.
- GPS location for operations management.
- Using GPS data to visualize fleet performance allows controllers to manage fleet in new ways. GPS data fed back to planning systems improves schedules. Monitoring third-party service provider in paratransit agency.
- Internet access so riders know when to leave offices to catch transit vehicle.
- Schedule adherence—Using data for real-time monitoring, use of data for analyzing route and schedule changes, customer complaint resolution, real-time passenger information. This allows us to monitor measurables for agency goals and adjust operations as needed. Use of these technologies has resulted in significant improvement in system on-time performance, use of historical data for schedule improvement, and significant changes for internal operating procedures.
- Data collection to improve schedules. On-time schedule adherence reporting, improved security, improved performance overall. Overall day-to-day operations have improved significantly over the years by reducing disruption of service, knowing where everything is, reduced early operation (no grievances ever filed for discipline based on the system), and increased security and feeling of safety by employees and passengers.
- GPS/vehicle tracking capability—Gives dispatchers the ability to track the buses. The availability of timely information is critical in day-by-day operations. Playback allows for confirmation of adherence and service levels.
- Schedule adherence data—Before implementation, we believed that our on-time performance was much better than what the system is telling us.
- Bus tracking and schedule adherence helps keep Central Command aware of situations out in the field.

Question 27. Please indicate the degree to which each of the following agency business units was involved in the effort to develop and implement your bus AVL system.

For responses regarding the level of involvement for various departments in the AVL system development and implementation process, Table 15 indicates that the percentage responding with a 4 or 5 (highest levels of involvement) were, in decreasing order:

- Operations—89%,
- Information Technology—73%,
- Planning—52%,
- Maintenance—50%,
- Security—25%,
- Customer Service—22%,
- Training and Human Resources—20%,
- Revenue—8%, and
- Marketing—8%.

The departments that most commonly had a significant level of involvement in developing and implementing the system were Operations, Information Technology, Maintenance, and Planning, the departments that would be most expected to be involved, because Operations uses the system, Planning maintains and uses the system data, and Information Technology and Maintenance support ongoing availability of the system hardware and software.

For certain departments expected to be affected by increased integration in the future between onboard AVL equipment and onboard equipment (e.g., revenue resulting from increasing farebox integration and security owing to increasing cameras integration), significant involvement in implementation could become more frequent.

TABLE 15
LEVEL OF INVOLVEMENT BY BUSINESS UNITS IN IMPLEMENTING THE SYSTEM

Business Unit	Not Involved 1	2	3	4	Significant and Ongoing Involvement 5
Operations	3.7%	0.0%	7.4%	18.5%	70.4%
Maintenance	15.4%	15.4%	19.2%	19.2%	30.8%
Customer Service	25.9%	22.2%	29.6%	11.1%	11.1%
Security	41.7%	20.8%	12.5%	20.8%	4.2%
Information Technology	3.8%	3.8%	19.2%	11.5%	61.5%
Planning	14.8%	18.5%	14.8%	22.2%	29.6%
Revenue	48.0%	24.0%	20.0%	4.0%	4.0%
Marketing	40.0%	32.0%	20.0%	4.0%	4.0%
Training and Human Resources	40.0%	20.0%	20.0%	12.0%	8.0%
Other	100.0%	0.0%	0.0%	0.0%	0.0%

Question 28. Please specify for any "other" response in the previous question.

For this question there were no "other" responses.

Question 29. Please indicate the degree to which each of the following agency business units are involved in the ongoing use and operation of your bus AVL system.

For responses regarding the level of involvement for various departments in the ongoing operation of the AVL system, Table 16 shows that the percentage responding with a 4 or 5 (highest levels of involvement) were, in decreasing order:

- Operations—92%,
- Information Technology—72%,
- Planning—62%,
- Maintenance—46%,
- Customer Service—46%,
- Security—27%,
- Training and Human Resources—9%,
- Revenue—4%, and
- Marketing—0%.

The departments most commonly involved to a significant degree in the ongoing use of AVL systems were the same departments involved with the development and implementation of these systems (i.e., Operations, Information Technology, Maintenance, and Planning).

Another department reported as significantly involved in operations was Customer Service, which is interesting considering that Customer Service was less commonly reported as being involved in implementation, as reflected in the responses to Question 27. This suggests that agencies should try to involve Customer Service in the implementation process more often. The typical involvement for Customer Service in using an AVL system is to use real-time information about bus status to help address customer questions or to help investigate formal complaints by consulting the archived data.

It is also interesting that none of the survey responses to this question identified Marketing as being significantly involved in the ongoing use of the system. It is possible that Marketing could identify some additional productive uses of the AVL system data if their involvement in AVL system operations increased.

Question 30. Please specify for any "other" response in the previous question.

For this question there were no "other" responses.

Question 31. Please indicate the number of staff [full-time equivalents (FTEs)] hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Operations business unit, in the revenue service phase for your bus AVL system.

Note that in Tables 17 through 25, each row represents the survey response from a particular agency, and the designations of "position #1" and "position #2" are to identify more than one position with any given response.

Another important type of effect is the extent to which implementing an AVL system leads to changes in the organizational structure, staffing, and job duties, as listed in Table 17. The following cites some examples from the survey

TABLE 16
LEVEL OF INVOLVEMENT BY BUSINESS UNITS IN ONGOING USE OF THE SYSTEM

Business Unit	Not Involved 1	2	3	4	Significant and Ongoing Involvement 5
Operations	3.8%	0.0%	3.8%	11.5%	80.8%
Maintenance	19.2%	3.8%	30.8%	23.1%	23.1%
Customer Service	12.5%	16.7%	25.0%	37.5%	8.3%
Security	36.4%	13.6%	22.7%	22.7%	4.5%
Information Technology	4.0%	8.0%	16.0%	24.0%	48.0%
Planning	19.2%	3.8%	15.4%	30.8%	30.8%
Revenue	47.8%	17.4%	30.4%	4.3%	0.0%
Marketing	40.9%	27.3%	31.8%	0.0%	0.0%
Training and Human Resources	39.1%	21.7%	30.4%	8.7%	0.0%
Other	100.0%	0.0%	0.0%	0.0%	0.0%

TABLE 17
STAFFING IMPACTS IN OPERATIONS

Position #1				Position #2			
Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided	Job Title	No. of FTEs Hired	No. of FTEs Retained	No. of FTEs Avoided
Dispatcher			6				
Data Administrator		1		Field Management Control		3	
Manager of Support Programs	1	15					
Road Supervisors/Other Operation's Staff	0	8	0				
Dispatcher			1	Transit Supervisor			1
IBS Coordinator	1	Technical Services Technician	1	MIS Database Coordinator	2		
Manager, TMS	1			Specialist, TMS	1		
Information Systems Analyst	1						
Operations Controllers (radio/CAD)	2						
Systems Analyst	1	20					
Transit Radio Dispatcher	0	0	0	Field Supervisor	0	0	4
Bus Operations Controllers		25					
Paratransit Dispatcher		5					
Street Supervisor			10				
Transit Supervisors	0	2	2				
System Administrator	1			Transit Supervisor—TCC	2	26	
Radio Controller (dispatcher)	1			Traffic Checkers			2 eliminated
Dispatcher		3					
Operators	0	500	0	Supervision	2	27	0
Program Manager	1			Communi-cations Supervisor	8		

FTE = full-time equivalent; MIS = Management Information Systems; TMS = Transit Management System; TCC = Transit Control Center.

responses for Operations, where there was a significant reported effect involving the hiring or retraining of staff, or where the need to increase staff was felt to have been avoided.

- Retraining for dispatchers, supervisors, and operators was commonly reported.
- Some agencies reported avoiding the need to hire additional dispatchers or supervisors, presumably based on service level increases that would normally have been expected to require additional staff.
  - In other words, if service levels were to increase without an AVL system in place the number of dispatchers and supervisors would normally need to increase. However, with the AVL system some agencies felt the existing staff was better equipped to absorb additions to the number of vehicles they need to manage.
  - Agencies could avoid hiring additional supervisors as a result of the dispatchers increased capability for dispatchers to have real-time situational awareness for the fleet, with correspondingly less need to rely on supervisors to serve as their "eyes."

Question 32. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Maintenance business unit, in the revenue service phase for your bus AVL system.

Another important type of effect is the extent to which implementing an AVL system leads to changes in the organizational structure, staffing, and job duties, as noted in Table 18. The following summarizes some examples from the survey responses for Maintenance, where there was a significant reported effect involving the hiring or retraining of staff, or where agencies avoided the need to increase staff.

- Agencies commonly reported needing to retrain maintenance staff or to hire to increase the overall number of maintenance technicians. The need to hire to increase the overall number of maintenance technicians would be expected because there are new types of equipment to be maintained and limited opportunities to decrease the amount of maintenance required on the existing equipment.

Montgomery County Ride-On (Maryland) reports that it added four maintenance staff in a position called "Transit Information Technician" to support its various types of transit technology. The Montgomery County AVL system was originally installed before 1997 and has been enhanced incrementally since then, including a current enhancement project. There were initially two Transit Information Technician positions established early in the life of the system to maintain the radio and other onboard AVL system equipment. The number of positions has recently expanded to four, owing to a combination of the increased fleet size and an expansion in the amount of onboard equipment (e.g., the addition of more onboard video equipment), despite the replacement of the fareboxes, which would tend to decrease farebox maintenance requirements.

TABLE 18
STAFFING IMPACTS IN MAINTENANCE

Position #1			
Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided
Radio Technician	5		
Running Repair	1		
Contracted Vendor for Maintenance			
Mechanics	0	8	0
Support Analyst, TMS	1		
Mechanical Technician	1		
Project Manager	0.5		
Electronic Tech	2	0	0
Electronic Technician	2		
Mechanics	0	2	2
Supervisor—Electronic Repair	1	9	
Technology Technician	1		
Communication Technicians	0	6	0
Transit Information Technician	4		

Question 33. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Customer Service business unit, in the revenue service phase for your bus AVL system.

Another important type of effect is the extent to which implementing an AVL system leads to changes in the organizational structure, staffing, and job duties, as noted in Table 19. The following summarizes some examples from the survey responses for Customer Service, where there was a significant reported effect involving the hiring or retraining of staff, or where the need to increase staff was felt to have been avoided.

TABLE 19
STAFFING IMPACTS IN CUSTOMER SERVICE

Position #1				Position #2			
Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided	Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided
Customer Service Rep.		12					
Customer Service Rep.		3		Dispatchers		5	
Customer Service Rep.		15					
Customer Service Agents	0	0	1				
Customer Service Rep.		8					
Information Clerk		2					
Customer Reps./Regional Information Operators	0	14	0	Supervisors	0	5	0

- Agencies commonly reported retraining for staff with customer service duties.

For the most part Customer Service Representatives were retrained, although in some cases retraining was also reported for dispatchers or supervisors (i.e., for agencies where these positions have some customer service responsibilities).

Question 34. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Security business unit, in the revenue service phase for your bus AVL system.

Another important type of effect is the extent to which implementing an AVL system leads to changes in the organizational structure, staffing, and job duties, as noted in Table 20. The following summarizes some examples from the survey responses for Security.

- Security—Staff hiring, retraining, or avoidance was not generally reported as significant.

Question 35. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Information Technology business unit, in the revenue service phase for your bus AVL system.

Another important type of effect is the extent to which implementing an AVL system leads to changes in the organizational structure, staffing, and job duties, as noted in Table 21. The following summarizes some examples from the survey responses for Information Technology, where there was a significant reported effect involving the hiring or retraining of staff, or where the need to increase staff was felt to have been avoided.

- Some agencies reported a modest level of staff retraining (and in some cases hiring). Considering the large degree of reported information technology (IT) involvement in AVL development, implementation, and operation it is interesting that agencies did not report more extensive retraining and hiring. This suggests that IT departments are focusing the support of the AVL system on a limited number of individuals from the overall IT staff, as opposed to equipping most staff to support the system. The limited hiring may also suggest that there is limited budget for new hires in IT, and that IT instead sometimes needs to add AVL system support to the already crowded workload of existing IT staff.
- Many of the responses involve a similar approach of hiring one new FTE position for IT support of the AVL

TABLE 20
STAFFING IMPACTS IN SECURITY

Position #1			
Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided
Security Supervisor	1		
Security Manager	1		

TABLE 21
STAFFING IMPACTS IN INFORMATION TECHNOLOGY

Position #1				Position #2			
Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided	Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided
System Administrator	2			Data Analyst	1		
ACS IT Support	1	0.5					
				Network Administrator	1	2	
MDT Specialist	1	5	0				
Manager, IT Network	1						
IT Technology Analyst/Programmer	2						
Communications Analyst	1	0	0				
				Comm./Network Specialist	1		
IT Technician		1					
Systems Integrators	1	2	0				
Technology Manager		1					
Network Support Staff	1	5	0				
IT Specialist	1						

system. In some cases this was coupled with retraining several of the existing IT personnel.

At PACE Suburban Bus in suburban Chicago, the AVL system introduction (see Table 6 for more on the features included in this AVL system) resulted in the addition of five FTE IT staff over four years. Four of these new FTEs were hired directly into the IT department to help with the IT support requirements of the new system. These requirements include tasks such as maintaining support data required by the applications, system databases, and data interface and communications. The fifth new IT FTE was an existing IT individual who was transferred into an IT support role with the users of the new system in Operations (with this position refilled within IT with a new hire). This involved retraining personnel to assist operations and dispatch in the use of AVL system data (T. Balvanyos, PACE, Arlington Heights, Illinois, personal communication, June 14, 2007).

In some cases, an agency may require an internal role for IT staff in systems integration, if the agency procures various individual components of an AVL system and undertakes to complete some or all of the required systems integration in-house. An example is the AVL system for OC Transpo (Ottawa, Ontario), which opted to procure MDTs and onboard MDT installation from external vendors but to develop its MDT/central software and overall systems integration using IT staff. Although this reduced the scale of capital expenditure required for the AVL system, there was an impact on IT staff. OC Transpo reported that it hired one additional FTE (and retrained two existing FTEs) to serve as systems integrators, even during the system implementation period before there was an operational system.

Question 36. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Planning business unit, in the revenue service phase for your bus AVL system.

Another important type of effect is the extent to which implementing an AVL system leads to changes in the organizational structure, staffing, and job duties, as noted in Table 22. The following summarizes some examples from the survey responses for Planning.

- For the most part agencies did not report much retraining of planning staff, a limited effect considering the potential opportunities for new or enhanced data analysis that come with implementing a bus AVL system.

TABLE 22
STAFFING IMPACTS IN PLANNING

Position #1			
Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided
Transit Planner		1	
Planning Analyst	1	8	
Planner		1	

The following provides some specific insights into an example of how the Planning function at one agency uses the AVL system and how it has affected its staffing (for Metro Transit in Minneapolis, Minnesota, which responded that Planning had hired one analyst and retrained eight more) (J. Hopper, Metro Transit, Minneapolis, personal communication, June 5, 2007).

- The Service Development Division is divided into four departments: Scheduling, Data Collection, Route and System Planning, and Service Analysis. This structure was in place before introducing the AVL system. Service Analysis has the responsibility for setting running times and frequencies of existing service.
- Planning had become short staffed for budget reasons and an analyst was hired in part to get the department back up to strength; however, introducing the AVL system helped provide the justification for this hire.
- The budget problems had also forced a reduction in the number of data collection staff from four to two. Metro Transit believes that it has been able to continue with this staff reduction in place as a result of the improved availability of on-time performance data from the AVL system.
- Metro Transit believes that the AVL system has changed how analysts do their jobs. The Service Analysis department was one of the first at Metro Transit to make use of AVL data, reporting on the data as soon as the Control Center had developed confidence in it and gave them access. Metro Transit had an earlier generation, more-limited AVL system before purchasing their current AVL system. Service analysis reports had been developed for the previous system that could be adapted to a new data source. However, in the last eight years since the new AVL became available, analysts have needed to adapt to having access to more AVL data. With the earlier system, the focus was on extracting information from a limited amount of AVL service performance data. With the new focus there has been a shift to sifting out what is actually happening from a flood of data, some of which is inconsistent and contradictory. The AVL data are currently the primary data source used at Metro Transit for setting running time in schedules.
- Metro Transit indicates that the retraining referred to in the survey response primarily consisted of helping the analysis staff get to and use the many AVL system reports developed for the Control Center. Service Analysis will commonly receive copies of these reports from the Control Center or supervisors to demonstrate a route schedule problem. There is also a system-wide on-time performance report used as a report card to guide its efforts.

As an additional example, as PACE in Chicago incorporated its AVL system into its operations it added an additional FTE (hired from outside) in its Service Analysis Department. These analysts help with processing data from the AVL system into information in useful form for users in the various business units (e.g., service analysis, planning, scheduling, marketing, and garages). PACE uses post-processed AVL data to determine passenger counts, on-time performance, and passenger miles. These data are provided on a monthly, quarterly, and annual basis, and are available on request. Post-processed AVL data are also used to create maps to display data on a geographic basis, for use by the Marketing Department, schedulers, and planners (e.g., for route restructuring analysis). Garages use the data to assign APC-equipped buses to those runs requiring APC data coverage (T. Balvanyos, PACE, Arlington Heights, personal communication, June 14, 2007).

Question 37. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Revenue business unit, in the revenue service phase for your bus AVL system.

Another important type of effect is the extent to which implementing an AVL system leads to changes in the organizational structure, staffing, and job duties. No staff effects were reported.

Question 38. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Marketing business unit, in the revenue service phase for your bus AVL system.

Another important type of effect is the extent to which implementing an AVL system leads to changes in the organizational structure, staffing, and job duties, as noted in Table 23. The following summarizes some examples from the survey responses for Marketing

- Hardly any staff effects were reported (there was one example of an agency reporting that there was some modest retraining to create some capability in the Marketing department for a “Data Reviewer”).

TABLE 23
STAFFING IMPACTS IN MARKETING

	Position #1		
Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided
Data Reviewer		0.5	

Question 39. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Training and Human Resources business unit, in the revenue service phase for your bus AVL system.

Another important type of effect is the extent to which implementing an AVL system leads to changes in the organizational structure, staffing, and job duties, as noted in Table 24. The following summarizes examples from the survey responses for Training and Human Resources

- A few agencies reported having to retrain some of their training staff.

Question 40. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in other business units (beyond the business units discussed in the previous sequence of questions), in the revenue service phase for your bus AVL system.

Table 25 summarizes reported staffing impacts in other areas of the organization beyond those inquired about in previous questions. One agency reported the significant impact of retraining operators and supervisors, which should be thought of as an impact in the Operations business unit.

Question 41. Please indicate the degree to which each of the following agency business units needed to adapt their organization and operations to use your bus AVL system effectively.

TABLE 24
STAFFING IMPACTS IN TRAINING AND HUMAN RESOURCES

	Position #1		
Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided
Safety and Training Manager		2	
Bus Operations Trainers	0	7	0

For the survey responses to the question regarding the degree to which departments needed to adapt their organization and operations to use the AVL system effectively, Table 26 indicates that the percentage responding with a 4 or 5 (highest degree of needed adaptation) were, in decreasing order:

- Operations—100%,
- Information Technology—62%,
- Maintenance—46%,
- Planning—42%,
- Customer Service—28%,
- Security—19%,
- Training and Human Resources—14%,
- Revenue—9%, and
- Marketing—5%.

The departments most commonly reporting that they required significant adaptation of their organization and operations to use the bus AVL system effectively are usually the departments responsible for the development, implementation, and operation of these systems (i.e., Operations, Information Technology, Maintenance, and Planning).

It could be worthwhile for transit agencies to consider the situation for the business units reported to have less need for adaptation of organization and operations (e.g., Marketing, Revenue, Training and Human Resources, and Security). There could be hidden opportunities to gain additional benefits from the use of the AVL systems if agencies were to fully consider whether adaptations for these business units might be beneficial.

TABLE 25
STAFFING IMPACTS IN OTHER BUSINESS UNITS

	Position #1				Position #2		
Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided	Job Title	No. of FTEs Hired	No. of FTEs Retrained	No. of FTEs Avoided
Bus Operators		1,465		Transportation Management		50	
Program Specialist	1						

TABLE 26
NEED FOR BUSINESS UNITS TO ADAPT ORGANIZATION AND OPERATIONS

Business Unit	Not Affected 1	2	3	4	Significant Changes Needed 5
Operations	0.0%	0.0%	0.0%	29.6%	70.4%
Maintenance	7.7%	19.2%	26.9%	30.8%	15.4%
Customer Service	16.0%	28.0%	28.0%	24.0%	4.0%
Security	38.1%	23.8%	19.0%	14.3%	4.8%
Information Technology	3.8%	7.7%	26.9%	26.9%	34.6%
Planning	11.5%	19.2%	26.9%	23.1%	19.2%
Revenue	45.5%	27.3%	18.2%	9.1%	0.0%
Marketing	40.9%	27.3%	27.3%	4.5%	0.0%
Training and Human Resources	31.8%	22.7%	31.8%	9.1%	4.5%
Other	100.0%	0.0%	0.0%	0.0%	0.0%

Question 42. Please specify for any "other" response in the previous question.

There was one "other" response to this question.

No impact on Training and HR staff. We originally planned for classroom training for drivers, but realized we could not take that many drivers off the road. We used a "train the trainer" approach, with brief individual classroom training followed by 4 to 8 h of behind the wheel training. Contracted service operators have incorporated MDT training into their driver training programs.

Question 43. Please indicate any of the following specific changes that were undertaken for each agency business unit, in order to adapt their organization and operations to use your bus AVL system effectively.

For this question Table 27 indicates that the most common responses for most departments were to "alter procedures" and to "provide training." The exception was Information Technology, where the most typical response was "increase staff."

Some of the particularly predominant responses for "provide training" were from Training and Human Resources, Marketing, and Customer Service. At least 25% of the responses from these business units indicated "provide training."

Some of the particularly predominant responses to this question for "alter procedures" were from Planning and

TABLE 27
CHANGES UNDERTAKEN TO ADAPT ORGANIZATION AND OPERATIONS

Business Unit	Increase Staff	Provide Training	Alter Procedures	Alter Organizational Structure	Other
Operations	19.2%	34.6%	34.6%	11.5%	0.0%
Maintenance	27.3%	31.8%	40.9%	0.0%	0.0%
Customer Service	0.0%	63.2%	36.8%	0.0%	0.0%
Security	10.0%	30.0%	40.0%	10.0%	10.0%
Information Technology	34.8%	26.1%	21.7%	17.4%	0.0%
Planning	0.0%	41.2%	52.9%	5.9%	0.0%
Revenue	12.5%	37.5%	50.0%	0.0%	0.0%
Marketing	0.0%	70.0%	20.0%	0.0%	10.0%
Training and Human Resources	0.0%	84.6%	15.4%	0.0%	0.0%
Other	0.0%	0.0%	0.0%	0.0%	100.0%

Revenue. Less than 30% of the responses from Training and Human Resources, Marketing, and Information Technology indicated "alter procedures."

Question 44. Please specify for any "other" response in the previous question.

The following "other" response returned:

- The greatest impact areas are in the Operations Division. It is assumed that all departments using or interacting with the system need training.

Question 45. Please indicate any of the following aspects of your bus AVL system where you feel the potential has not been fully utilized to date, as a result of adaptations yet needed to the organization and operations to use it effectively.

In response to this survey question, Table 28 shows that the most common responses were TSP, next arrival predictions, and paratransit scheduling and dispatch.

Question 46. What was the one biggest challenge associated with adapting agency organization and operations to implementing and operating your bus AVL system?

There were many interesting and varied responses to this question. Noted challenges include:

- Underestimating the degree to which advance planning was needed;
- Ensuring support from IT, maintenance, and other parts of the organization; and
- Adapting business practices and operating procedures.

The following responses were provided:

- Training the drivers and the dispatchers.
- Project was delayed by several years owing to failure of initial contactor. The second contractor had technical challenges that compromised system operation. Once we resolved technical issues and made the data available to business units, they adapted relatively quickly.
- The biggest challenge was getting agency staff to accept system-collected data as valid. The evaluation metrics usually involved comparing historically collected data (manual) against machine-collected data. Because of the larger scope of data collected, it was nearly impossible to accurately compare data for validation purposes.
- Defining a system "owner" after the implementation was complete.
- Ongoing maintenance of the product without vendor support (out of business).
- Not a single challenge, but a difficult one: Adapting business practices and operating procedures to a totally new way of doing business. We are still working through this one.
- Getting the staff to use it.
- Training bus operators.
- Handling the data in dispatch.
- Customer education.
- Not having a high level of IT talent within the agency from the outset.
- Training and IT system support and administration.
- Schedule interface (implementation)—Hardware maintenance (operations).
- Subcontracted bus operators: Failure to keep AVL equipped on correct routes and/or maintain and operate AVL system properly.
- Training maintenance and operations employees while still maintaining "normal" business operations. Vendor coordination, attempting to get the work done while not interfering with operations.
- Maintenance.
- Getting comprehensive needs early in project.
- Lack of knowledge of the amount of advance planning required.
- Introduction of GPS-based monitoring of vehicle locations.
- Ensuring that commitments made by departments were honored through the life of the project, resources assigned, and remaining focused on project objectives.
- Monitoring the system for accuracy.
- System roll-out, including installation timeline meeting requirements and staff training.
- Funding.
- Schedule data modifications.
- Running data reports on the system we have now is now easily done. The upgraded system that is in the works will offer many reports that will be easy to get for all users.

TABLE 28
TECHNOLOGIES WHERE FURTHER ADAPTATION NEEDED TO FULLY UTILIZE

Technology	%
Transit Signal Priority	43.8
Next Arrival Predictions	34.4
Scheduling and Dispatch Software for Paratransit Operations	31.3
APCs	28.1
Next Stop Announcements	21.9
AVL Software for Fixed-Route Operations	18.8
Other	0.0

Question 47. Please indicate any of the following uses your agency has adopted for archived data from your AVL system.

TABLE 29
USES FOR ARCHIVED DATA

Uses	%
Scheduling	78.1
Planning	71.9
Maintenance	37.5
Marketing	15.6
Third Part Research (e.g., universities)	15.6
Other (please specify)	12.5

As shown in Table 29, scheduling and planning were the most common responses to this survey question. Another reported use was for following up on customer complaints.

Question 48. What was the biggest way in which your bus AVL system has met or exceeded the expectations the agency had when the decision was made to deploy?

Different parts of a bus AVL system were cited as having met or exceeded initial expectations. These included location, schedule adherence, and passenger counts tracking, as well as the ability of the agencies to both improve operations and generate useful passenger information from this tracking. Another improvement noted was in introducing transfer automation in the form of Transfer Connection Protection (see the Beaver County Transit Authority case study for additional information about its implementation).

The following specific responses were provided:

- Real-time passenger load tracking along with schedule variance tracking.
- The initial project scope did not include the idea of using AVL data for customer information. The University of Washington developed some customer applications as a research project, and they have been widely accepted by our customers.
- The use of historically collected data is the biggest way the systems integrator has exceeded expectations. In addition, the use of real-time vehicle position data has been a highly visible and successful component of the system.
- A reasonably accurate and near real-time means of approximating "where" the bus "is" or "was"/"when."
- Vehicle location to respond to service concerns.
- The ability to know where each vehicle is at every moment has been very valuable. We have also been able to use MDT/AVL data to revise our scheduled running times by distance and time of day.
- Useful in verifying customer complaints.
- On-time performance.
- Customer feedback.
- The value of the stop-by-stop passenger count information.
- System performance monitoring has been improved, operating data collected, and security and communications with buses improved.
- Daily recap reports. Better communication between fixed-end and vehicles.
- Better reliability. Replaced obsolete no longer serviceable equipment. Reliable passenger count information.
- RSA.
- Practical customer service representative use in providing current system information to customers.
- System information.
- Enhanced efficiency in management of revenue service.
- Ability to monitor service performance in real time, improve on-street performance and on-time stats.
- Convenience for system patrons.
- Reporting capability for performance measurement and monitoring and security use (an example is a hijacked bus).
- Although on-time performance was lowered by default, overall performance of day-to-day operations has improved as well as timetables. Customer service reports are investigated using the system and the feeling of improved security has increased.
- Automation of transfers.
- On-time performance.
- Communication, schedule adherence, and monitoring are main functions of the AVL/CAD.

Question 49. What was the biggest way in which your bus AVL system has not met expectations the agency had when the decision was made to deploy?

The responses were quite varied. One response about a system that cannot provide location when reroutes are in effect refers to a signpost-based system and so is not representative of most current AVL systems because these are GPS based. Some relatively frequently mentioned items for which expectations varied from reality relate to:

- Longer-than-expected systems integrator implementation schedule.
- High level of effort needed for managing the systems integrator implementation effort.
- Extent to which leading edge promised features were delivered (e.g., web-based access to real-time passenger information).
- Limitations in APC data accuracy.
- Limitations in onboard equipment interoperability and vendor independence owing to implementations of the J1708 standard with vendor-specific elements.
- Limited post-implementation support from systems integrators.
- Level of ongoing maintenance needed for system components and data.
- High level of effort required for data management and reporting.

- Inability to meet expectations for staff reductions.
- Resistance to accepting validity of system data that varies from data gathered using more conventional methods (e.g., on-time performance data).
- Resistance to adopting procedures that would decrease voice radio traffic.

The following specific responses were provided:

- The APCs are not as accurate as we expected them to be.
- There is no single issue that meets these criteria. Owing to technical limitations, the system does not perform well under conditions when you might need AVL data the most; that is, adverse weather when many reroutes are in effect. Ultimately we have gotten about as much out of this system as we possibly could, given its constraints. It took quite a while to resolve some of the initial technical issues, before we reached the point where the data were useable.
- The system was originally thought to be able to reduce the number of "in-field" staff for supervision. Unfortunately, we have not been successful for a couple of reasons. First, there is a need for field supervision to provide customers with immediate service; second, there is the need for a presence to detour misconduct. Third, system reporting has not been accepted as valid owing to comparisons with manual collected data. Supervisors continue to be required to manually collect on-time performance data.
- Use of route schedule adherence tool and expectation of automating status and available bus for transfer.
- Ongoing issue owing to lack of vendor support.
- We have had a higher incidence of unit failure than expected. It took us 2.5 years to reach the acceptance standard of 95% of scheduled events performed by MDTs. In retrospect, I would have purchased more spares and required military-grade cables, connectors, and flash memory cards.
- Trouble keeping it in operation.
- Data management.
- It is extremely time consuming to ensure the data integrity within the system.
- Polling rate could be higher for a higher level of location accuracy.
- Developing improved schedules using archived data.
- Operational reliability and usability.
- Reliability. Inoperable onboard equipment and failure to make internal passenger information announcements.
- Ease of managing contractor technical deployment.
- Web-based customer trip planning.
- Length of time required to deploy the system.
- Twenty percent over budget and difficulties meeting schedule.
- Working through APC to timepoint assignment issues. Implementation timeline.
- System was to be plug and play; did not meet the J1708 standards. Not nearly integrated enough with other systems and funding continues to be a problem with updating, replacement, and/or expansion.
- Reporting capabilities and accuracy.
- We expected a much greater reduction in over-the-air voice traffic.
- Reliability issues.

Question 50. What was the one biggest challenge associated with effectively integrating your bus AVL system with other agency technology?

There were some interesting specific issues included in the agency responses.

- For the export of schedule data from fixed-route scheduling software, the run data needs to be reconciled and adjusted so it will work well with the AVL system.
- Integrating paratransit scheduling and dispatch management software requires a real-time communications interface with the MDTs, which has proved challenging.
- Network integration issues arose such as time synchronization between servers and finding space for additional servers.
- Onboard integration was challenging owing to the need for integration with products from multiple vendors (e.g., farebox, headsign, and APC).
- Turnover in IT staff made maintaining the overall integrated system an ongoing challenge.

The following specific responses were provided:

- The biggest challenge at the time, the early 1990s, was getting the routing and scheduling data aligned so that the system had good baseline data to operate on. The tools for doing this have improved greatly since then.
- The biggest challenge was integrating the ACS (AVL system) with the paratransit dispatching system. Issues with the interfaces between systems became complicated with problems of both vendors pointing fingers.
- Synchronizing "time" and keeping all related databases at same state of update. Most of the discrete subsystems have their own "clocks," often making it difficult to consolidate data from differing sources and assuming the common "field" to be date/time.
- Eighteen months to install and accept.
- Restoring the system after a gateway or mobile carrier failure. Queued AVL records overwhelmed the scheduling/dispatch software.
- Still working on it.
- AVL software talking to paratransit scheduling software.
- Finding room for the additional servers.
- Have not been able to integrate the AVL with the fareboxes owing to proprietary vendor issues.
- Data exchange with other agencies has yet to be accomplished.
- Schedule integration.

- Proprietary system attitude by technology providers; not willing to interface.
- Stand alone system with little integration. Vendor installation while not impacting operations was a challenge.
- Integration with scheduling software; coordination with existing scheduling software timepoints and AVL timepoint requirements.
- Creating effective reports.
- Advance planning.
- Managing the interaction of individual vendors regarding the interfacing of their systems.
- No real issues in this area.
- Staff resources and coordinating project timelines.
- IT staff turnover and a subsequent lack of engagement.
- Using the data to drive passenger information signs and schedule predictions.

Question 51. What was the one biggest challenge associated with managing the development and implementation of your bus AVL system?

Some challenges noted largely focus on:

- The need for strong project management, including the use of agency leadership, dedicated agency staff, and technical support consultants to effectively manage the implementation process and the systems integrator.
- The need to manage expectations and avoid scope creep, based on how the system is initially justified to gain approval and how business units respond as they gradually gain increasing awareness of the potential of the system for their area and the changes in business practices that will be needed.

The specific responses were as follows:

- The biggest challenge at the time was getting the contractor to resolve the punchlist of open issues toward the end of the project. Ultimately we agreed on a settlement, and went on to make substantial technical revisions to the system using our own resources. It took about 3 years to reach the point where the system performed as well as it should have at the time of final acceptance.
- The one biggest challenge was getting management to buy-off on the capability of the system and to manage expectations. Generally, if managers bought-off on the system, they would begin to expect that the system would do things that were not originally advertised resulting in disappointment.
- The time period between the project being complete/contractor winding down and our agency ramping up (i.e., the fixed-route acceptance was a rather long period to gain contract closure; consequently, the transition was a bit painful for both parties).
- Using a consultant proved to be very helpful in creating and implementing the project.
- Making the huge shift in business practices.
- Staff buy-in and cost.
- Keeping the databases up to date.
- Staff training and development.
- Not having the IT talent on staff.
- Regional cooperation and implementation.
- Poor (no) project management; for example, no staffing management plan, no roles and responsibilities assignment.
- Slow and inflexible responses to customer needs.
- Identifying and retaining system subject matter experts within agency to serve as project managers and project integrators.
- Importing of scheduling database.
- Keeping contractor on schedule.
- Staff training.
- Managing employee expectations and their acceptance of change.
- Scope creep: Many clients saw possibilities of technology, difficult to maintain control of scope. Vendor not flexible with change management issues. Too much of development costs for the system borne by agency, not by vendor. Contract weak in some areas.
- Money.
- Ensuring the technology meets the agency requirements and expectations.
- Conflicts with vendor.
- Staff time: Staff was pulled into this project as an addition to their normal tasks.
- Not really a problem, but it takes a lot of different people that are responsible for tasks that they are assigned and there are times when one person or department can hold up the project.

The PRTC in Northern Virginia implemented an innovative bus AVL system that combined MDTs in support of a flexible route demand-responsive service. Much of the technology used in this deployment was new or customized (GreyHawk MDTs, Trapeze FLEX software), and it was also being newly integrated. The overall effort began in the mid-1990s and the systems integration effort was not completed until 2001–2003. The PRTC Project Manager offers the following lessons learned for any agency developing and implementing an AVL system, in particular if it involves new development from the systems integrator or an innovative application (E. Marx, PRTC, Woodbridge, Virginia, personal communication, May 29, 2007):

- Expect to need lots of staff involvement in ITS projects.
- Use independent external technical help to write a tight specification, but realize there will still be many unanticipated or unaddressed issues.
- Get Project Manager buy-in on the implementation timeline.
- Use a single Project Manager to be in charge and to serve as a central point of contact.

- Make sure your contract has "teeth" (e.g., liquidated damages), and require that the systems integrator do the same with subcontracts, to help ensure timely performance.
- Expect the project to take up two to three times the original timeline, despite agency planning efforts.

Question 52. What was the one biggest challenge associated with selecting the systems integrator for your bus AVL system?

Challenges commonly reported focused on the limited number of systems integrators with proven experience, and on the limited time and experience available among agency staff that had to make difficult decisions involving unfamiliar technologies. One agency also noted that it was required to implement its system through a low-bid procurement, which is not considered the most effective approach for an advanced technology systems implementation.

The following specific responses were provided:

- At the time, we had only one competitive bid, so there was not much choice.
- The number of integrators available at the time of procurement. In the late 1990s a contraction in the market occurred where one vendor bought out two other contenders and the other major vendor stopped marketing its system. The reduced number of vendors resulted in lower competition.
- The overall radio system upgrade was initiated in the late 1990s and required a digital radio frequency communications infrastructure, possibly a bit ambitious at that time/state of proven technology.
- N/A. We had decided we wanted a PC-based MDT with an existing interface with Trapeze PASS. At the time we procured, there was only one vendor. Our next procurement will offer multiple choices.
- Not many affordable systems available for a small agency at the time of procurement.
- As a growing transit system, finding a vendor that was flexible to grow and work with us.
- One who could integrate different components in one system.
- Insufficient agency knowledge of applicable technologies.
- That will happen later this year.
- Procurement process was low bid.
- Validating their experience.
- Determining which vender had the best product and experience.
- Finding an affordable solution—different climate in Canada than the United States. Ended up assuming greater risk than was comfortable with.
- Ensure the selected vendor best meets our needs, requirements, and has the capacity to handle/grow with an agency fleet of our size requirements.
- Funding.

TABLE 30
BENEFIT/COST ELEMENTS NEEDED TO SECURE APPROVAL TO PROCURE

Element	%
Capital Costs	78.1
Operating Costs	78.1
Measurable Benefits	75.0
Subjective Benefits	56.3

- Finding an integrator who would customize to suit our needs, but also ensure that we continue to get updates as the system matures.
- The learning curve with the technology. Operations staff on the panel did not have sufficient IT experience.
- Has not been a problem.

Question 53. Please indicate which of the following needed to be estimated as part of gaining approval to implement your bus AVL system.

As shown in Table 30, the most commonly reported types in the survey responses were capital costs, operating costs, and measurable (quantitative) benefits. Subjective (qualitative) benefits were also reported as commonly used for pursuing approval. The availability of quantitative benefits is an ongoing challenge considering that many of the agencies that have deployed bus AVL systems to date have not systematically measured the benefits they experienced.

Question 54. Please indicate any of the following factors that were important in gaining approval to implement your bus AVL system.

The most common survey responses in Table 31 were "improve operating efficiency," "improve reporting or analysis capability," "improve safety and security," and "improve public information." These influencing factors appear to be reasonably aligned with the potential benefits of bus AVL systems.

TABLE 31
IMPORTANT FACTORS IN GAINING APPROVAL TO PROCURE

Factor	%
Improve Operating Efficiency	84.4
Improve Reporting or Analysis Capability	84.4
Improve Safety and Security	78.1
Improve Public Information	68.8
Modernize Public Image of Transit Agency	37.5
Benefits Expected to Exceed Costs	37.5
Other (please specify)	9.4

It is interesting to note that one of the less commonly reported factors was "benefits expected to exceed costs." This likely indicates that agencies recognize that many of the benefits are difficult to quantify, which makes it challenging to show benefits exceeding costs in purely numeric terms.

Question 55. What was the one biggest challenge associated with gaining approval to implement your bus AVL system?

Common responses included obtaining funding, justifying adequate benefits to rationalize the cost, and working through the agency approval procedures.

The specific responses were:

- Owing to the failure of the initial contractor, it was difficult to obtain funding to proceed with the second contractor.
- Determining a cost benefit based on objective criteria. This was especially true for options such as passenger information systems.
- Fortunately the decision was easy, as our previous system was quite old, becoming unreliable and the software was difficult to support (i.e., a replacement radio system was needed and adding the "AVL" component was a natural).
- Funding, very expensive project for midsize properties.
- We had a staged procurement: A 3-vehicle proof of concept, followed by a 30-vehicle, 30-day test. A budget proviso required that we report a successful result from the 30-day test to our county council before funds for rollout could be released.
- Proving it would be useful.
- Demonstrating the system's benefits compared to cost—an on-going effort.
- Convincing political management of AVL benefits.
- Operator acceptance.
- Initial capital cost.
- Cost.
- Securing sufficient funding.
- Lack of budget flexibility for investment.
- Identifying funding.
- Initial costs.
- Uncertainty of accurate cost/benefit information.
- Cost.
- Calculating a return on investment.
- Overcoming concerns with how recordings could be used.
- Costs!
- Working through bureaucracy of local government—satisfying political objectives, as well as project goals. Times for approval often very long, caused great deal of frustration.
- Gaining acceptance for AVL as a benefit for organization needs.
- Funding.
- Funding.
- This push toward the technology came from the top, so it was not too difficult.

Question 56. What was the one biggest challenge associated with defining the functional capabilities for your bus AVL system?

Challenges in this area focused on the difficulties of:

- Limiting the functional requirements to those capabilities truly needed,
- Establishing internal consensus, and
- Judging what features were available as proven and cost-effective features from a reasonable number of the systems integrators.

Some responses noted the usefulness of complementing the in-house experience with experienced outside assistance, such as from a specialized consultant. It was also noted that agency staff are expected to have an easier time effectively scoping a bus AVL system when it is a replacement of an earlier system rather than a first-time effort, a situation that will become more common over time.

The specific responses were:

- At the time, we did not have a clear sense of how the operation would change or what features would be most useful. The system replacement project that is currently in progress does not face this issue; the users are very clear about what they need and how they want it to work.
- Understanding the capabilities and limitations of the systems. In our case, we pushed the envelope on a couple of add-ons only to learn that although the vendors said they could deliver, in the final analysis, they could/would not.
- Coverage and underestimating the impact of local cellular interference in the 800 MHz spectrum.
- Used a consultant. Very helpful.
- Merging the recommendations of the radio expert from the consultant group we hired to perform a business analysis with what was actually available in the marketplace.
- As mentioned earlier, with a growing system, capturing and defining current and future needs during the procurement process.
- Financing it.
- Defining the needs of multiple partners participating in the purchase and implementation of a new AVL system.
- Taking into consideration developing needs and capabilities during the system life cycle.

- Cost versus functionality (would have liked to install on light rail vehicles, and purchase Dynamic Passenger Info system at the same time). Would have liked to integrate with other coach sub-systems such as engine diagnostic data.
- Lack of expertise with operating departments for seeing/using advantages.
- Limiting it to practical benefits, rather than flashy technology for its own sake.
- Training.
- Determining the practicality of each individual component/function.
- Knowledge of the different systems available, changes in technology and the interface with different system components from various vendors.
- Determining desired tradeoff between picture quality and storage capacity.
- Getting all the departments to agree on components they wanted/needed in a system.
- Getting agreement from various departments within transit agency on project goals and ownership.
- To have a reality check on agency wishes/vision versus current available market technology.
- Compatibility with other systems and future expansion capabilities.
- Getting different areas of the agency to agree on functional capabilities.
- Incremental cost versus the benefits for customized changes/enhancements.

Question 57. Please identify which agency resources were involved in each of the following stages that have been completed for bus AVL system development at your agency.

The majority of agencies responded that agency business unit staff was involved in all stages of the deployment process (Table 32). A smaller but still substantial portion of the responding agencies indicated using dedicated agency project management staff as well. This is often useful owing to the complexity and scale of the deployment, coupled with the ongoing heavy workloads typical of transit agency staff.

Consultants are an additional resource applied selectively by agencies, commonly reported as supporting technology assessment, functional specifications, projects definition, needs assessment, implementation planning, solicitations, and implementation management and evaluation. Agencies would in general likely benefit from increasing the effort placed in selecting best value proposals, ensuring that system integrators deliver on their proposal commitments, and measuring project benefits.

Question 58. Please describe any additional "lessons learned" that would benefit transit agencies that are considering bus AVL systems.

Survey responses provide specific, varied, and detailed feedback on this topic. Some key themes include:

- Understanding the importance of building and maintaining stakeholder participation from throughout the organization.
- Planning for procurement of the actual functionality needed by the agency, including required integration with other systems.
- Understanding that a substantial and ongoing effort will be needed for system configuration, maintenance, and data management.
- Taking enough time for careful selection of the systems integrator and for application of strong project management to the implementation.

TABLE 32
SUPPORT RESOURCES INVOLVED IN IMPLEMENTATION PROCESS

Support Resouce	Agency Business Units Staff	Agency Dedicated Project Management Staff	Consultants
Needs Assessment	59.4%	40.6%	46.9%
Technology Assessment	53.1%	43.8%	68.8%
Projects Definition	62.5%	40.6%	59.4%
Implementation Plan	59.4%	53.1%	46.9%
Project Approval	78.1%	50.0%	15.6%
Functional Specifications	50.0%	50.0%	68.8%
Solicitation	65.6%	50.0%	28.1%
Selection of Systems Integrator	62.5%	50.0%	37.5%
Implementation Management	56.3%	59.4%	25.0%
Evaluation	59.4%	50.0%	31.3%

Specific responses are as follows:

- Stakeholder participation is a critical requirement for building support and acceptance for system deployment. That participation can take a lot of time that you do not want to spend on the front of the project but will pay off later.
- Agencies should be aware of the substantial time commitment necessary for initial data load and clean-up. Although vendors say they do it all, in fact there are several items that are better left to agency staff. Keep vendor to schedule. Do not allow vendor to put off items to other phases. The result is the most difficult items for the vendor to complete pushed to the back of the project resulting in completion delays. Agencies should try to purchase software off the shelf with little modification. This will reduce the time necessary for software modifications and repairs down the road.
- Clear definition of expectations and means of test to quantify acceptance, caution toward forced integration to legacy systems, minimize proprietary protocols/software, Request for Proposal (RFP) should include warranties/extended exercisable service agreements/periodic technology upgrades, clear terms/phased milestones throughout the project (payments and approvals to proceed to next step) and define performance (i.e., area/zone/corridor coverage, location accuracy, plus/minus real time, reliability, redundancy, and maintainability).
- If you are integrating multiple systems, do one at a time for acceptance purposes.
- Use industrial/military grade cables, connectors, and cards. Get the most rugged units available. Be realistic about the number of spares you need. Anticipate that devices will need dedicated staff to support them.
- Buy local and understand what the operating costs will be each year.
- The amount of staff time needed to be devoted to keep the system functioning so that the data are usable, and the amount of coordination within the agency to make sure all of the components are functioning properly.
- Make sure the AVL system "talks" to other software.
- Be prepared to make alterations at the start to meet your intended objectives.
- You need to have full-time dedicated IT staff to make the project successful. You need to constantly train and retrain operators and dispatchers.
- Clearly define needs and expectations. Ensure that technically competent and knowledgeable staff is assigned to project. Ensure the cooperation by other work units or disciplines required.
- Read TRB reports. Talk to other project managers. Have a risk management plan and be guided by the Project Management Institute's project management processes.
- Diminishing benefits from signal priorities in complex transport systems (intersecting routes, conflicting needs).
- If possible install on all modes (bus and light rail). Include CAD–AVL–Pass information in one system; ensure AVL accuracy sufficient for passenger information.
- Need to have a dedicated system administrator on board from design onward; electronic technician dedicated to support installation and maintenance both in control center and field.
- Cannot emphasize enough the need for operations staff/management to define needs at the start in nontechnical terms to provide the functional and performance foundation to build to.
- Planning system set up.
- Agencies should base their specification and contract on proven, "off the shelf" technology.
- Our timeline was compressed owing to matching funds being taken away. I would advise any agency who is interested in purchasing an AVL system to give themselves plenty of time to do a proper evaluation of the product. Many vendors say that they can or have provided the product you are looking at to another property but in all actuality they may have done something similar to what you are purchasing.
- Ensure agreement and sign-offs in place throughout project lifecycle. Important to constantly reassure approvals from labor groups still valid—they often change their minds, especially if new executive. Keep all stakeholders informed of status. Expect delays and challenges at every stage. Be realistic when setting expectations, schedules. Ensure sufficient financial support—allow at least 20% contingency. Control project scope tightly.
- Plan for delays in schedule; ensure the technology matches your current and future agency needs. Do not let the current technology limit your agency vision, use a good systems engineering approach to develop a concept of operations plan.
- Planning, look ahead for future upgrades and integration with other systems.
- Imperative that you allocate sufficient resources, not only during the implementation stage but also to maintaining the system after installation.
- Spend more time with peer agencies that have implemented. Do not be pressured into too many decisions while still early in the project. Structure your payment milestones to include a final holdback for unresolved issues.
- I would suggest having a service agreement in place at all times with the vendor.

Question 59. Are there other agencies you would suggest we should speak to regarding "best practices" in bus AVL systems? If so, please provide contact information.

The following specific responses were provided:

- TriMet in Portland, Oregon, would be a good choice.
- Bakersfield, California.

- Spokane Transit; TriMet, Portland, Oregon; Kitsap Transit; WMATA; Dallas DART; Houston Metro.
- Kansas City Area Transportation Authority, Long Beach Transit, Lane Transit, PACE, MetroTransit—Minneapolis.
- Grand River Transit, Translink Vancouver, Houston.
- Regional Transportation District (RTD) Denver.
- VästTrafik in Göteborg, Sweden.
- SF MUNI and Orleans France (cellular-based passenger information system in Orleans).
- C-Tran—Vancouver, Washington; Pierce Transit—Tacoma, Washington; King County Metro, Seattle, Washington.
- San Diego Transit Corporation.
- Long Beach, California; Kansas City, Missouri; Portland, Oregon.
- Niagara Frontier Transportation Authority.
- Los Angeles County Metropolitan Transportation Authority.

Question 60. If your agency has not yet decided to implement a bus AVL system, what is the biggest reason?

The responses include issues such as understanding the needs and technologies sufficiently, securing funds, and delays until an associated technology such as the communications system will be replaced.

The following specific responses were provided:

- Further deployment to fixed route is dependent on more urgent needs (voice radio replacement) and capital funding availability, both being pursued.
- Understanding available technology and costs of implementation.
- Procurement in process—cost is an issue
- We are going to implement an AVL system. We are going though the evaluation process right now (February 4, 2007).
- We are upgrading our system.

CHAPTER FOUR

CASE STUDIES FROM TELEPHONE INTERVIEWS

This section provides more detailed information on selected bus AVL system implementations. The following profiled implementations were selected from survey respondents to provide diversity in geographic location, fleet size, system integrator, and AVL system functionality (see Table 33):

- Beaver County Transit Authority in Rochester, Pennsylvania (Pittsburgh region).
- King County Metro in Seattle, Washington.
- Triangle Transit Authority in Raleigh–Durham, North Carolina.
- Valley Metro in Phoenix, Arizona.

BEAVER COUNTY TRANSIT AUTHORITY—ROCHESTER, PENNSYLVANIA

The BCTA AVL system case study is largely based on a detailed interview with BCTA senior staff Renee Mosura and Mary Jo Morandini, who were closely involved in system development and continue to be involved in its operation. BCTA provides service in Beaver County, a suburban area within the Pittsburgh, Pennsylvania, region centered on Rochester, Pennsylvania, with a service area of 440 square miles.

BCTA used an earlier generation of bus AVL system in the early 1990s that has since been replaced, originally selecting the then-emerging Loran-C location tracking technology over signpost technology. Loran-C was a navigation support system of terrestrial transmitters operated by the federal government, through which vehicles could receive signals allowing the triangulation of current position. In some ways, this was a transitional technology toward the GPS systems, which operated on similar principles using satellite-borne transmitters. With the full launch of GPS in 1995, the federal government began to phase out the Loran-C system.

The overall BCTA experience with the initial system had been positive, and BCTA took steps to begin a transition to a GPS-based AVL system that would also incorporate some of the more recent AVL system capabilities available. In 1999, BCTA developed specifications, leading in 2000 to RFP issuance and the selection of Siemens Transportation Systems (now Siemens VDO) as the systems integrator. Once BCTA completed the negotiations and contracting process was completed early in 2001, it began the implementation effort. In mid-2001, subsequent to the design process, system installation began. System acceptance testing started in 2002, and Siemens achieved a conditional system acceptance in 2003.

The new AVL system included an MDT and VLU, with an integrated GPS receiver and covert alarm switch. Vehicles were also equipped with APC. The two major transfer centers were equipped with next-arrival-prediction DMS. The system functionality included Transfer Connection Protection (TCP), which BCTA has found very useful for their transfer-intensive mode of fixed-route operations.

The TCP feature of the BCTA system allows the operator of a vehicle incoming to a transfer location to send a text message to the AVL system that indicates the route to which a passenger would like to transfer. Based on a policy as to the maximum time the outgoing vehicle should wait if the incoming vehicle is delayed, the system can determine whether the outgoing vehicle should hold based on real-time schedule adherence and inform both vehicles. The main benefit is that if the incoming bus is late enough that the outgoing vehicle would need to hold too long, the outgoing vehicle can be released earlier rather than holding for nothing.

BCTA has equipped 32 fixed-route vehicles, 4 of which also support demand response operations in a route deviation mode. These vehicles operate on a fixed route with a reduced number of stops, but also deviate for advance scheduled demand response trips on a paper manifest only within the route corridor. The initial system did not replace the paper manifest on these vehicles.

BCTA has found many features of the current system to be very useful, such as:

- Dispatchers have an improved ability to easily know where fleet vehicles are at all times.
- Customer service staff informs callers of the current location for their bus, and use the playback feature to investigate the validity of complaints.
- Planners use the data on actual running times and dwell times to justify changes that have made schedules more realistic and effective.
- The transfer center arrival prediction DMSs are popular with customers, in particular during the area's harsh winters; these DMSs are located within the transfer center interiors and thus provide information while allowing passengers to wait inside.

TABLE 33
OVERVIEW OF CASE STUDY AGENCY AVL SYSTEMS

Agency	Reported Fleet Size	Systems Integrator	Year Completed	AVL System Functionality
Beaver County Transit Authority	11–50	Siemens VDO	2003	• AVL central software • MDTs with GPS • APC • DMS for real-time passenger information
King County Metro—Fixed Route	1,201+	Harris (current) INIT (to be implemented)	1994 (current) 2010 (expected completion for new system)	• AVL central software • MDTs (with GPS only in new system) • Interior and exterior onboard announcements (new system only) • APC • DMS for real-time passenger information (new system only) • Interface to web real-time passenger information service • Interface to traffic signal control system for transit signal priority (new system only) • Onboard interfaces to headsigns and smart card reader (new system only)
King County Metro—Paratransit	101–300	Greyhawk	2006	• MDTs with GPS • Integration with paratransit scheduling and dispatch software • Integration with IVR for real-time passenger information
Triangle Transit Authority	51–100 (fixed-route) 1–10 (paratransit)	Radio Satellite Integrators	2007 (nearing completion)	• AVL central software • MDTs with GPS
Valley Metro	301–600 (fixed-route) 101–300 (paratransit)	Orbital Sciences	2005	• AVL central software • Radio communications • MDTs with GPS • Interior and exterior onboard announcements • APC • DMS for real-time passenger information

The primary staffing impact has been the addition to maintenance of an ITS specialist. In addition to the operating cost impact of the additional staff support for maintenance, there is an annual cost for spares and system support services from Siemens.

Information technology (IT) and data analysis support for the system are time consuming; however, BCTA has found that they were able to accommodate these needs with its original staff of two in this area. BCTA has also purchased additional software (DataPoint, supplied by Avail Technologies) beyond the reporting capabilities available with the Siemens AVL software. The reporting software allows agency personnel to view farebox and APC data in a flexible manner to assist with data management, analysis, and reporting, without the need for extensive user training.

Overall, at this point BCTA believes that it still needs to take additional steps to adapt its business processes and get more of the potential benefits available from having the AVL system. For example, they believe that dispatchers do not yet fully exploit the system's potential. BCTA plans to undertake a comprehensive organization-wide quality assurance assessment in the near future, with one of the anticipated outcomes being the identification of changes in business processes that could help take best advantage of the available tools such as the AVL system.

BCTA has current plans for AVL system enhancements that would incorporate additional capabilities that have become established features for bus AVL systems in recent years. It has largely defined an upcoming Phase II of system development, which includes:

- Updated central system computer hardware and operating systems;
- WLAN for bulk data transfer at the garage;
- Onboard next stop announcements;
- Upgrades for demand response equipment to replace paper manifests, through integration with the recently implemented Routematch paratransit scheduling and dispatch management software;
- Integration with the existing GFI Cents-A-Bill fareboxes; and
- Integration with headsigns.

BCTA has already secured grant funding for a Phase II system enhancement project effort with Siemens. Phase II is also expected to incorporate an onboard smart card reader. BCTA is currently collaborating with Port Authority Transit in Pittsburgh and other regional transit agencies on this smart card project. It may wait for regional consensus in this area before proceeding with the overall Phase II effort, because the specific nature of the required farebox integration (or integration with a separate stand-alone smart card reader) will be affected.

Beyond the current planning for Phase II as a near-term initiative, there are further plans for a medium-term effort to expand to Phase III. At this point, the key features already allocated for Phase III are more extensive features for real-time traveler information, building on the initial popularity of the transfer center DMS. These are expected to include making more information available through the agency website, including both AVL system data such as next stop arrival predictions and current vehicle locations as well as an online ticket purchase feature. BCTA is considering making these capabilities available through an IVR telephone system.

Other aspects of the current system that BCTA considered as areas of desired improvement include:

- Improved AVL data interface with and reporting tools for maintenance.
- The ability for the AVL system to automatically determine and incorporate into the system data the actual location of stops, in particular when these are periodically adjusted or there are route changes (i.e., to avoid the need for time-consuming stop location data collection by staff).
- The potential need to update the communications system is also an issue, considering that the channels used are in the 450 MHz band and may be affected by the Federal Communication Commission frequency refarming initiatives.

KING COUNTY METRO—SEATTLE, WASHINGTON

King County Metro (KC Metro) provides service in King County, Washington, which includes the city of Seattle, some of its surrounding suburban cities, and more rural areas of the county to the east. It has operated as part of the King County DOT since 1994, with a roughly 2,000 square mile service area. Services offered include fixed-route bus with a fleet of more than 1,400 vehicles, Dial-A-Ride Transit deviated route vans, ACCESS Transportation Americans with Disabilities Act (ADA) paratransit with approximately 290 body-on-chassis vehicles, the George Benson Waterfront Streetcar Line (service temporarily suspended as of April 2007 as a result of downtown construction), and Elliott Bay Water Taxi (a summer-only service). The ACCESS service area is approximately 1,100 square miles, of which about 800 square miles is land area. KC Metro also operates some Regional Express bus service under contract to Sound Transit.

The "Transit Now" initiative passed by voters in 2006 provides a 0.1% sales tax for a 20% expansion in bus service over the next ten years, including the introduction of four "Rapid Ride" BRT routes. Other transit services in the region include Community Transit, Everett Transit, Kitsap Transit, Pierce Transit, Sound Transit (commuter buses, commuter rail, and light rail), and Washington State Ferries.

This case study separately discusses the fixed-route and paratransit AVL systems, because KC Metro operates independent systems for these purposes. The Dial-A-Ride Transit deviated route vehicles are not currently equipped under either of these AVL systems.

Fixed Route

The fixed-route portion of the KC Metro AVL system case study is largely based on a detailed interview with KC Metro employee Dan Overgaard, who was closely involved in system development and continues to be involved in its operation.

The fixed-route fleet is currently equipped with a bus AVL system that uses roadside beacons ("signposts") technology rather than GPS. Buses receive the transmitted identification while passing a roadside beacon, store that data along with the current odometer reading, and send current odometer and signpost encounter updates to the central system over the radio every 90 s. The poll response packet provides the identity of the previous signpost passed, the odometer reading at the time of the encounter, and the odometer reading since the start of the run; these data are matched against the scheduled geographic pattern to calculate the vehicle location (with the implicit assumption that it remains on route). The signpost beacons are located roughly 2 to 3 miles apart along each fixed route.

One challenge with a signpost-based system is the need for ongoing maintenance of the distributed roadside beacons, which are battery operated. The system has more than 300 beacons, and typical battery life is approximately 3 years. An inherent limitation is that during inclement weather, KC Metro implements numerous reroutes (to avoid operation on certain hazardous hilly streets) and this can result in many signposts being missed with a corresponding loss of location data (or signposts on a different route being detected). Also, KC Metro needs to relocate signposts when routes are occasionally altered.

Implementation of this current AVL system began in the early 1990s. The RFP was issued around 1988. One motivation for proceeding with AVL deployment at that time was the need to replace the voice radio system, which created an opportunity to combine implementation with an AVL system. Also, KC Metro believed that it was ready based on lessons learned from an abortive AVL system attempt in the mid-1980s. KC Metro received several proposals, and awarded a contract to Harris in 1989.

The initial emphasis was on achieving voice radio coverage in the downtown transit tunnel, which opened in 1990. Subsequently, the project installed a new voice and data system, and operated in voice-only "fallback" mode while it tested the data system and installed the fleet equipment. Ultimately, it implemented the full system in 1994. The system was usable but also had several fairly important remaining deficiencies, and a settlement was reached in which KC Metro kept a portion of the system payment. One issue was a tendency for the MDT software to freeze, which was of particular concern because it prevented even voice radio communications with the vehicle. Another issue was a tendency for the covert alarm switch to give off excessive false activations. The systems integrator did not offer a support program that was satisfactory to KC Metro and within a few years exited the transit ITS line of business entirely.

KC Metro initiated various in-house efforts to complete needed retrofits and enhancements, and to support the system itself. A former subcontractor from the project with expertise in their MDTs was successful in upgrading the MDT software to avoid the freeze-up issue.

AVL system data coverage, in terms of the number of daily timepoint crossings for which the system could calculate schedule adherence data, was originally only about 60%. This was too limited to support effective use of these data by planning staff for on-time performance assessment and schedule refinement. Over time, this was improved and KC Metro indicates that this data coverage is currently consistently more than 90%.

At this point, a variety of different departments at KC Metro consider the current AVL system as essential to their operations. KC Metro realized significant benefits to scheduling when the agency added a HASTUS analysis module, which can receive AVL data and help schedulers perform statistical analyses of running times and update their running time estimates. Other examples include how Customer Service and Operations use the system to research customer complaints and operator grievances, and how on-time performance data as reported by the system have been adopted by management as one of the key system performance indicators.

The University of Washington developed tools to use the tracking data to provide real-time public bus information through the Internet, originally as a research project (*31*). KC Metro hosts this technology under the name "Tracker," which provides both real-time departure predictions for specific timepoints and displays a map view showing the most recently reported bus locations.

KC Metro has over the past decade or so of using the original AVL system developed many other enhancements, and has also needed to adapt and evolve the system to accommodate the ongoing computing technology:

- The custom geographic data originally used in the system has evolved to use a GIS map as input, and the system now includes a map display with multiple layers of data elements available.
- The central system user interface was originally written for the DEC operating system and included proprietary

elements to the 386 chipset. This user interface software was in time rewritten to allow a migration to PC-based computer hardware and the Windows operating system. The dispatchers participated in the design and testing of this interface, and KC Metro indicates that it was pleased with the results.
- The system polling and vehicle location calculation algorithms were entirely rewritten by KC Metro staff to provide more accurate and complete data.
- The reporting features of the original system were limited to a printout of the incoming data reports from the vehicles. With the advent of modern database management and reporting tools, KC Metro has implemented a variety of enhancements for data storage, processing, analysis, and reporting.
- KC Metro has had an operational APC system since the 1970s. There was no attempt to integrate this APC system at the time of AVL implementation, and the two systems originally used duplicate signpost systems with different signpost beacon communication protocols. KC Metro eventually adapted the APC equipment to use the same signposts as the AVL system, and also completed some onboard integration that provided for a single operator login to both systems.

The current AVL system has required an ongoing level of in-house support for making effective use of the system as well as for providing system support services that were not available from the systems integrator. This has included a dedicated staff of eight maintenance technicians and three dedicated IT staff for data management and reporting, and for processing the incident logs.

KC Metro is currently replacing the fixed-route AVL system with a GPS-based system implemented by the bus AVL systems integrator INIT. The challenges in maintaining the current AVL system continue, and the features of the AVL systems available today are increasingly attractive.

The AVL upgrade is part of a broad strategy to update KC Metro's onboard systems, starting with a smart card-based Regional Fare Collection System. The onboard smart card reader requires an operator interface, and the existing AVL system control head was not adaptable to this purpose. The plan is to implement a new operator interface as part of the smart card system, which will then in turn serve as a building block for AVL system replacement. Smart card system deployment was delayed by the loss of a regional transit funding source in the late 1990s. All three projects were placed on hold for a several years until funding was restored. KC Metro indicates that it is now on track to deliver an integrated suite of onboard applications, with smart card rollout scheduled for 2008 and the AVL and radio system implementations scheduled to be completed in 2010.

The FCC's "refarming" timeline for the ultra-high frequency (UHF) band, issued in the mid-1990s, imposed a critical deadline for replacing the existing 450 MHz voice and data system. Given the tight integration of the radio and AVL systems, KC Metro determined that both should be replaced, but decided to approach these as separate but related procurements.

KC Metro continued work on the design and specifications for the AVL system replacement while the project was on hold, so that KC Metro was ready to move quickly once this decision was made. The RFP was originally issued in 2004, and a contract was issued to the AVL systems integrator INIT in March 2007. It awarded the parallel radio system replacement project to Motorola, who started work in 2006, and awarded the smart card system contract to smart card systems integrator ERG Transit Systems in 2003. As of April 2007, work on the AVL system replacement project was underway, and the King County Program Management Office will oversee coordination between INIT, Motorola, and ERG to develop the best possible overall integration in the overall system. The new communications system is scheduled to be completed in 2009, with bus AVL onboard installations starting in 2009 and fleet migration expected to be completed in 2010.

One interesting consideration for KC Metro at this point is how to best transition from one operational AVL system to another. An additional complexity for the cutover is that the current AVL system dispatch center is housed in a building that requires seismic upgrades, which has led KC Metro to decide to build a new dispatch center location for the replacement AVL system. The original concept had been to have the two dispatch centers operating in parallel during the cutover, meaning that dispatching for individual vehicles could simply be cutover from one dispatch center to the other as they were re-equipped. The challenge arose when KC Metro determined that there were not enough experienced dispatchers available to support this approach. As a result, KC Metro relocated the dispatchers to the new control center before the start of the transition, with a remote connection to operate the existing radio infrastructure from the new location. As the agency brings the new system into operation, the plan is for dispatchers to operate both systems for a time from this new location.

It will install the replacement AVL system on its 1,400 to 1,500 revenue vehicles (the specific size of the fleet by the time of installations is currently uncertain), and the system is to include the following capabilities:

- MDTs with covert alarm.
- Next stop announcements, including audible and DMS announcements.
- Exterior audible announcements of route and destination information when the door is open at the stop.
- APC, initially on 15% of the fleet.
- TSP, with the approach of providing current schedule adherence (and for APC-equipped vehicles also pro-

viding the current vehicle passenger load) to the traffic signal system to assist its decisions on when to grant priority.
- Integration with the headsigns and the smart card reader to automatically signal the route and the start of each trip.
- Limited monitoring and real-time transmission for certain critical maintenance alarm conditions.
- Next arrival prediction DMS at selected stops are to be added in a subsequent phase, initially focusing on the five BRT corridors to be implemented starting in 2010.
- The system will continue to feed data to the University of Washington system for the Tracker online traveler information system. The agency will reassess the desirability of additional updates to the KC Metro web presence and customer services after system implementation.
- WLAN infrastructure is already in place at garages to support bulk data transfer with the onboard video monitoring camera systems that have already been installed on approximately 100 vehicles; however, the AVL system (and the smart card system) will use this WLAN infrastructure as well.

In a separate project, the agency will equip service supervisor vehicles with a fixed mounted workstation in the vehicle with a cellular data card configured to allow for access to the KC Metro WAN, and all standard enterprise applications such as e-mail and the county intranet. As part of this WAN access, it is intended that the system will give supervisors real-time access to selected information from the new AVL system and the ability to run reports in the field.

Paratransit

The paratransit portion of the KC Metro AVL system case study is largely based on a detailed interview with KC Metro staff Janey Elliott and Michael Glauner, who were closely involved in system development and continue to be involved in its operation.

The ACCESS Transportation paratransit service vehicles were equipped with a separate AVL system in 2004 (*32*). This system equipped all paratransit vehicles with MDTs supplied by Greyhawk Technologies (see Figure 4). These MDTs use a larger format touchscreen, and ACCESS believes the operators appreciate the larger format buttons and text that this technology allows. The MDTs are integrated with a GPS receiver and the vehicle odometer, and use mobile data communications to exchange data with the PASS paratransit scheduling and dispatch management software from Trapeze Software. The system is installed at four operating bases used by three different operations contractors.

The MDT core functions are to download and update the manifest, provide trip events completion data in real time, and support text messaging between operators and dispatch. Other features include:

FIGURE 4 ACCESS paratransit van MDT (*Courtesy:* Doug Parker, TranSystems).

- A recent effort to convert the MDT odometer interface to use the digital odometers with which some newer vehicles are equipped by connecting the MDT to monitor the J1708 diagnostic port. However, ACCESS indicates that this has not always been successful.
- Mapping navigation software, which provides turn-by-turn instructions from the current vehicle location to the upcoming pickup or dropoff, although it does not provide audible instructions.
- A popular added feature suggested by one of the ACCESS operators allows an operator to request current traffic condition data from the Washington State DOT website.
- Enhancements to the customized MDT screen for operator pre-trip inspection input.
- A supervisor version of the MDT, with the same features as the MDTs for the revenue vehicles plus an extra feature to access the current manifest status for a selected vehicle. This feature has been limited to only accessing a limited portion of the selected manifest to limit the amounts of data being downloaded.
- Greyhawk is currently developing a wireless software update capability, which would be valuable because it would allow ACCESS to avoid the time-consuming process of visiting vehicles individually whenever the MDT software requires an update.

Overall, ACCESS management believes that although it needed significant effort and time to complete this system, the end result was very worthwhile and transforming. They would not want to go back to the conventional operation used before this implementation. Overall, productivity has increased from about 1.6 to about 1.7 passengers per vehicle-hour, and ACCESS management believes that a large part of this improvement can be reasonably attributed to the introduction of this system. Productivity is a fundamental measure of cost-effectiveness in paratransit; therefore, this improvement of more than 6% is significant. It represents the incremental improvement in productivity with the introduction of the MDTs alone, on top of the productivity improvements associated with the earlier introduction of the paratransit scheduling and dispatch management software.

The implementation process began in 1996 when funding was secured to begin the planning and development to add AVL capability to the existing PASS scheduling and dispatch management software. Planning began with a study in 1997 that recommended installing MDTs for the fleet that would communicate with the existing software using Cellular Digital Packet Data (CDPD), which was the commercially available technology of that time supporting mobile data transmission over a leased cellular telephone system account. ACCESS had broadly based staff participation in the study, including operators, mechanics, dispatchers, and call-takers.

Other key considerations were that the selected technology should use a previously proven interface with Trapeze PASS, and that the MDT should use a PC-based operating system to support any potential future expansion of the software. The marketplace was relatively limited for paratransit-oriented MDTs at that time, and with these requirements ACCESS concluded that Greyhawk Technologies was the only suitable alternative. This led to KC Metro's approval for a sole-sourced procurement in 1999, a provision of which was requiring a successful test of the technology with a 30-vehicle subset of the fleet as a condition of the approval to proceed with the full fleet rollout. ACCESS had broadly based staff participation in the early phases of implementation, including operators, mechanics, dispatchers, and call-takers.

The deployment contract with Greyhawk was established in 2001. By June 2002, ACCESS had completed a successful test with 3 vehicles, followed by a 30-vehicle test in September 2002. As a result of this progress, KC Metro released funding for the full fleet rollout in 2003.

A complication arose during the period of the full rollout resulting from to the phasing out of CDPD technology. Cellular carriers in the region were shifting to the next generation of cellular-based mobile data technology: either 1xRTT or General Packet Radio Service (GPRS). ACCESS conducted testing for the services available with these alternatives, and they selected GPRS-based service from AT&T. ACCESS uses 5 MB per month service plans for each vehicle, which costs $19.99 per month minus a 5% government discount. Because ACCESS had already outfitted 30 vehicles with CDPD technology, there was an additional delay while Greyhawk integrated their MDTs with the new GPRS modem and retrofitted the modems in the previously installed MDTs.

All vehicle installations were completed in April 2004. Although the PASS interface was supposed to be an established part of the Greyhawk technology at the time of contract award in 2001, the interface was not operating entirely to the satisfaction of ACCESS until 2005. The Greyhawk contract also included a performance requirement that each vehicle must perform with on average at least 95% of the trip events completed using the MDT for 30 consecutive days. This standard was achieved in October 2006, and as of April 2007 ACCESS indicated that the system was consistently performing well, with fewer than 25 vehicles on any given day completing less than 90% of their trips by means of the MDT.

ACCESS believes that the relatively long time needed to achieve system acceptance after the MDTs were installed and the PASS interface was in place might have been reduced if the MDTs had incorporated more ruggedization features for use in transit vehicle conditions. For example, they suggest specifying military standard cables and connectors. Although there was a 10% spare ratio and this currently appears adequate, they found that during the implementation period there was a frequent and ongoing need for MDT replacement as equipment failed in service and there were not always enough spares available.

ACCESS has also incorporated IVR integration into their AVL system. PASS has incorporated their INFOserver module, which can trigger the IVR system to complete an automated reminder call to the customer as the vehicle approaches for their pickup. The operator presses a button on the MDT, which sends a message to PASS that triggers the IVR call. ACCESS has also created in-house software that allows the dispatcher to directly trigger an IVR call to a customer if needed.

PASS only updates estimated trip event times for manifests when trip events are performed, but not for location reports enroute. Therefore, if a vehicle is delayed enroute, the manifests do not reflect any delay until the first trip event is affected. To help improve on this, Trapeze developed the capability to insert phantom operator breaks into the manifest (i.e., breaks with zero duration that would be marked as completed on the MDT as the vehicle passes the "checkpoint"). The resulting intermediate trip event data achieves an intermediate update to the estimated completion time for the remaining trip events in the manifest. With this approach, times are recalculated based on the reported GPS location for the break to the geocoded location of the pickup or dropoff.

One other problematic aspect of MDT operation has been that after an outage of the mobile data communications system, the MDTs "flood" PASS with all of the data accumulated during the outage. Although the trip events data must eventually be collected, it is questionable whether the agency needs to accumulate location reports. In any case, the way this is being managed is that the gateway software that processes incoming messages has now been configured to process trip events messages with a higher priority when there is a backlog of incoming messages.

ACCESS uses the system in various additional ways beyond its core function for managing daily fleet operations and automating the distribution and completion of manifests.

- The data have been used to calibrate parameters in PASS that affect vehicle scheduling to best fit actual operating conditions. This includes, for example, examining actual passenger load and unload times for comparison with the corresponding scheduling parameters in PASS.
- AVL data have also been used to assess the correct response to passenger complaints (e.g., vehicle arrived late or passenger no-shows). In many cases this has resulted in the exoneration of the operator when the system data support their statement on what occurred, whereas in other cases the data can indicate where the agency can use operator counseling.
- Another use for the system data has been to monitor the extent to which operators are pulling out for their runs on time.
- To help assess the extent to which MDTs are performing the scheduled events rather than by dispatch, a "snapshot" of the baseline PASS schedules are stored at about 4 a.m. before the start of the operating day and before any trip editing has been performed.

One interesting aspect of how ACCESS uses the system is that they continue to distribute a paper manifest and have the operator mark up the manifest as trip events are completed, whether or not the MDT is operating. This ongoing redundant effort for the operators provides a backup for ACCESS, but may in time change if confidence in the MDT system continues to increase.

The main effect on staffing was that ACCESS had to create an MDT Specialist position in the IT department. This individual was originally one of the operators with a contractor who had been involved early with the implementation effort and also had an aptitude/interest in training other operators and supporting the system. The MDT Specialist took a strong role in liaison with Greyhawk during the implementation process and has subsequently continued in the role after the implementation to support effective operation and maintenance of the equipment. During the implementation period when the level of required support effort was most intense, an additional person from the IT department was assigned to support the project about half time. ACCESS staff believes strongly that this dedicated support was critical to the success of the project. One other impact on staffing has been to train maintenance technicians and supervisors to perform first-tier troubleshooting, such as swapping out a failed MDT with a spare unit, so as to minimize vehicle downtime.

ACCESS is currently planning and designing efforts to replace the MDTs with current generation equipment, with an implementation target of 2010.

TRIANGLE TRANSIT AUTHORITY—RALEIGH–DURHAM, NORTH CAROLINA

The Triangle Transit Authority (TTA) AVL system case study is largely based on a detailed interview with staff member Laurie Barrett, who was closely involved in system development and continues to be involved in its operation.

TTA was created as a regional public transportation authority by the state in 1989 to serve Durham, Orange, and Wake counties, including portions of the Raleigh–Durham urban region often referred to as the Triangle. It operates regional fixed-route and paratransit operations, and is in the process of developing a regional rail system. TTA cooperates with several other public transit providers in the region, including Chapel Hill Transit, Durham Area Regional Transit, Capitol Area Transit, Cary C-Tran, Orange County Public Transportation, North Carolina State University, and Duke University.

TTA starting developing its fixed-route bus AVL system in 1999, receiving three responses to an RFP issued in 2000. A contract was awarded to Radio Satellite Integrators, who started installing the system on 68 buses in late 2000. This system includes an onboard MDT with an integrated GPS receiver and CDPD cellular mobile data communications. The MDT sends location reports to central dispatcher software and also supports text messaging between operators and dispatch. The system also includes an onboard covert emergency alarm button integrated with the MDT.

Once cellular service providers announced the phasing out of CDPD mobile data technology, TTA pursued having the system updated to use the new Code Division Multiple Access (CDMA) cellular data technology. When CDPD service was discontinued in late 2005, the system had not yet been upgraded and had no mobile data communications for some time. An operational pilot version of the updated MDT with CDMA support was received by 2007, and as of April 2007 TTA was integrating the updated system with the central software.

Although the use of cellular mobile data technology involves significantly reduced capital costs relative to implementing an agency-operated mobile data system, this illustrates that the underlying technologies used by cellular data systems will evolve at least every few years. Although the transition from CDPD was one of the first such transitions and came as a surprise to many agencies and vendors, agencies using cellular mobile data systems today can now anticipate and plan for these transitions. This primarily involves communicating proactively with the cellular service provider and the technology vendors, and budgeting for the periodic minor upgrades required to maintain compatibility with the cellular data service as it evolves and improves.

Use of the initial TTA bus AVL system has indicated that the benefits were gained from its use to verify customer complaints and reduce voice radio traffic through MDT text messaging. An AVL system with more consistent mobile data communications capability is also expected to provide benefits from comprehensive and reliable on-time performance reporting.

One implication of this delay for TTA was that in 2006 it lost its staff member who had the most experience with the system, having worked with it since 2001. At this time, TTA is considering hiring a new IT staff member to manage the development and operation of a regional AVL system expansion. This would be contract staff funded collectively by TTA and other participating regional transit providers.

In 2005, TTA purchased new GFI Odyssey fareboxes. When the AVL system was implemented, TTA buses were equipped only with mechanical dropboxes. The new fareboxes were implemented with the J1708 wiring needed to support future integration with other onboard systems. The farebox procurement was an initial exercise in regional collaboration on transit technology development, with multiple agencies purchasing the same farebox together (an exception is Chapel Hill Transit, which operates fare-free and does not need fareboxes). A current regional effort is planning the trial deployment of APC equipment for 7 to 8 buses as a pilot.

Current planning for regional transit technology collaboration is pursuing a real-time traveler information system, for projected completion in 2009, with efforts for agency-level approvals and funding applications. The new system would provide next arrival predictions through DMS at selected stops as well as through websites and potentially IVR systems. This effort is building on the limited-scale deployment of this type of technology already undertaken by Chapel Hill Transit using technology from NextBus. The agencies are aware that this type of system must have a comprehensive and reliable AVL system at its core and intend to replace the current bus AVL system with new regional bus AVL capabilities as part of the overall real-time information system procurement.

VALLEY METRO—PHOENIX, ARIZONA

The Phoenix/Valley Metro AVL system case study is largely based on a detailed interview with city of Phoenix Public Transit Department staff Mike Nevarez and Bob Ciotti, who were closely involved in system development and continue to be involved in its operation.

Valley Metro (city of Phoenix Public Transit Department) is a voluntary member organization whose members include the city of Phoenix; it provides service in Maricopa County, Arizona, which includes most of the Phoenix metropolitan area as well as more rural areas of the county. The official name for Valley Metro is the Regional Public Transit Authority (RPTA), which provides an overall regional transit identity (the Valley Metro identity was adopted in 1993). Valley Metro Board member agencies include Avondale, Chandler, El Mirage, Gilbert, Glendale, Goodyear, Maricopa County, Mesa, Peoria, Phoenix, Queen Creek, Scottsdale, Surprise, and Tempe. Other regional services provided by RPTA on behalf of its member jurisdictions include customer service, marketing, and long-range planning.

Transit services include fixed-route bus, commuter bus, BRT, neighborhood circulators, and paratransit. These are generally operated by individual members (e.g., Phoenix, Tempe, and RPTA) using contractors. About 75% of all Valley Metro routes are operated by the city of Phoenix Public Transit Department. Light rail service is currently under construction, with initial service to connect the cities of Phoenix, Tempe, and Mesa.

A bus AVL system was implemented between 2002 and 2005 to support the operations of all the Valley Metro agencies on approximately 770 fixed-route buses, 220 paratransit vehicles, and 60 support vehicles. This case study focuses on the use of this AVL by the largest single individual agency operator in the region, the city of Phoenix Public Transit Department. Phoenix operates transit over a fixed-route and paratransit service area of approximately 400 square miles. One feature of the system yet to be completed that is important for the Valley Metro institutional context is data sharing between agencies. Phoenix also found the need for collaboration, coordination, and consensus between multiple regional agencies to be a challenge during the system design, procurement, and implementation stages.

The origins of the bus AVL system in the Phoenix region date back to 1996. Regional transportation agencies in Phoenix received federal funding to develop one of the Metropolitan Model Deployment Initiative (MMDI) regional multimodal ITS system demonstration projects (the four MMDI sites were New York/New Jersey/Connecticut, Phoenix, San Antonio, and Seattle). In the Phoenix region, the MMDI was branded as "AZTech," and the MMDI deployment contract was awarded in 1998.

Multimodal ITS integration was a requirement in these efforts and it included a bus AVL demonstration system project. TRW Transportation Systems was the prime contractor for AZTech systems development and integration, and Advanced Digital Systems implemented the bus AVL demonstration. This bus AVL system equipped 70 vehicles with AVL and contributed real-time schedule adherence data to the AZTech regional traveler information systems; it was implemented for approximately $500,000. This prototype system used CDPD for mobile data communications and provided some traveler information using DMS at stops.

The need emerged around this time to replace the existing Phoenix trunked voice communications system, under a regional initiative where the new system would support the needs of all the Valley Metro member transit agencies.

Building on the experience with bus AVL in AZTech, it was decided to implement a comprehensive bus AVL system as part of the regional communications project. It was considered advantageous to integrate the design of the radio mobile data communications system needed for the bus AVL system into the overall design of the voice communications system.

The other regional member agencies were engaged in designing the system and in selecting the systems integrator. The multiple agency system development process used stakeholder committees, with representatives including operators, maintenance workers, union representatives, and management. There was some emphasis in the design process on establishing consistent operating procedures and reporting to allow the various agencies and contractors that are involved to make effective use of a single shared AVL system. Other areas developed collaboratively included maintenance, training, integration, and networking.

The city of Phoenix Public Transit Department conducted the procurement because it is the largest of the regional agencies operating as Valley Metro and has the greatest capacity to manage such a substantial effort; it awarded the contract in 2001. The procurement process included a site visit to review a similar system nearby in Las Vegas, Nevada. All the agencies implemented the AVL system that was completed in 2005, which is referred to locally as the Vehicle Management System (VMS).

The systems integrator was Orbital Sciences, and the overall system included a new and expanded capacity radio communications system from Motorola (*32*). This overall AVL system includes the communications system, AVL software, APC (with about 15% of the fleet equipped), next stop interior/exterior announcements, a WLAN for bulk data exchange at garages, and 19 real-time bus arrival information DMS at selected stops.

The central servers used by all agencies are housed in the city of Phoenix, with the other regional transit agencies using these servers by means of remote consoles. The other agencies in the region purchased their own workstation hardware for the remote consoles, and paid their own staffing costs for system operations and maintenance. Each regional partner pays the costs for the WAN links they use to connect to the central servers. The agencies are currently considering issues related to cost sharing for network administration and ongoing central system maintenance and support costs.

Onboard integration with the VLU includes the installation of covert alarms and microphones, a limited number of headsigns, and the Scheidt and Bachmann fareboxes. The system was implemented with the intent of expanding to include TSP, in particular for BRT operations. Another feature under consideration is integration with their onboard video monitoring system.

Longer-term cost containment—the ability to be able to accommodate future system growth with reduced need for additional staff—was a key factor in securing approval to implement the system. Initially, some additional skills were needed in the organization. This was addressed through a combination of additional training for certain existing staff, coupled with new hires in some key areas. Another resource that they have found effective for the initial phase of operations is the Orbital Resident Project Manager required under the contract through the five year warranty. There was a dedicated project manager during implementation, but this dedicated role was transitioned out after acceptance. Operations is currently responsible for compliance monitoring for warranty purposes.

Overall, Phoenix believes that some of the most effective ways it has been able to use the AVL system is for performance monitoring, safety and security, customer service, and passenger information. Phoenix has hired some additional staff to help best take advantage of the system's potential, including two VMS controllers (i.e., dispatchers) and two data analysts. The additional IT efforts have centered on database management, application systems administration, and network administration.

Initial uses of archived system data were primarily for scheduling, planning, and maintenance. They believe they still have a lot to learn, but have started to identify specific new opportunities for how to use the data in a manner that cuts across departments. For example, APC data can be used by planners to improve scheduling and to comply with NTD reporting requirements for ridership data. Initial efforts with reporting have largely focused on establishing a set of concise and useful performance monitoring reports for management use. The set of standard reports provided with the system has been supplemented with various additional reports developed using the ad hoc report development features of the system. Report export, using an eXtensible Markup Language (XML) interface for allowing external access on the overall agency LAN and publishing data to other regional agencies, will be added as a feature to help increase the usefulness of reports.

In general, the role of the VMS controller has expanded relative to before AVL. The communications system supports an AVL polling rate of 120 s, and their early experience suggests operations would benefit if the system could support a shorter polling interval to provide enhanced information on current vehicle locations.

They also believe that they have not used the full potential of some aspects of the system, including APC, TSP, and the next arrival predictions DMS. With the system still in its first few years of operation this was largely a deliberate choice, through placing the initial emphasis on making effective use of the core AVL, communications, and next stop announcement aspects of the system and deferring detailed exploration of these other features.

There is currently a shift in emphasis to fully develop the potential for all capabilities of the system, including a current focus on monitoring on-time performance, tracking service interruptions, and monitoring pullouts (especially for the emerging BRT service). Managing the configuration of the next stop announcements data and the disposition and analysis of logged incident reports have emerged as areas that require significant ongoing effort.

A police transit bureau was recently initiated with the City Police Department, with five sworn officers, a number of supporting supplementary unsworn security officers, and a fleet of 10 transit police patrol vehicles. These vehicles would be equipped with both police and transit radios, so dispatch will be able to request security support for onboard incidents. These vehicles are equipped with MDTs for VMS controller awareness of their locations.

Having been in place for a couple years, VLU is starting discussions with Orbital about the potential hardware and software evolution needs of the system. In particular, the Orbital system was one of the last implemented using a previous generation of onboard hardware with an integrated VLU and operator interface. The current generation of Orbital equipment uses a separate VLU to enable more extensive onboard integration, and Orbital also now offers an operator interface with a color display.

The new communications system operates in the 450 MHz band, and is expected to be capable of accommodating fleet expansion up to approximately 1,200 vehicles at the current location polling rate and level of data use. They are participating in a regional consortium considering an eventual transition to the 700 MHz band, which will in time become necessary as a result of spectrum refarming initiatives in the 450 MHz band, but expect to be able to continue using the 450 MHz-based system for some time. Motorola has recently indicated that they will be discontinuing support for the onboard radios used in the current system, which is another factor being considered regarding the life cycle of the current radio system.

CHAPTER FIVE

HOW AUTOMATIC VEHICLE LOCATION SYSTEMS ARE IMPLEMENTED AND USED

This section provides an overview of how transit agencies implement and use bus AVL systems. There are two distinct phases in the life cycle of a bus AVL system: the system acquisition phase (design, procurement, and implementation) and the revenue service phase (after system acceptance). During the system acquisition phase, all affected departments need to be involved in the process to help ensure that the system is designed and configured to meet their needs. In the revenue service phase, the emphasis shifts to adapting procedures so as to best support the new system and take advantage of the new opportunities it offers.

For the survey responses to Question 41 regarding the degree to which departments needed to adapt their organization and operations to use the AVL system effectively, those with a high percentage responding with a 4 or 5 (highest degree of needed adaptation) were in decreasing order:

- Operations—100%,
- Information Technology—62%,
- Maintenance—46%, and
- Planning—42%.

MANAGEMENT

The impact of implementing and operating an AVL system on agency operations is substantial and cuts across all the major business units in the organizational structure. The requirement for extensive internal coordination and collaboration is often a significant challenge for a transit agency, because the various business units are not often required to collaborate in this manner. Mechanisms to require and facilitate such collaboration sometimes do not exist or are rarely used. It is also essential that senior management communicate a vision for the end results intended from the technology implementation plan, coupled with clear direction on required collaborative procedures. An additional key role for management is in ensuring that staff is made available for training and in providing additional resources in departments where needed.

The evident commitment of senior management to the project and the leadership of a project champion are important steps to convey that these information gathering and coordination activities are essential. The project champion is usually a member of the agency's senior management team, and often does not have sufficient availability to directly coordinate these activities. It is common for one or more agency staff to be assigned project manager responsibility for AVL system implementation (with the backing of the project champion). The specific approaches to how project management for AVL system development is fit with the agency organizational structure can vary, with the following as examples for some current implementation efforts at agencies of varying sizes (each of these implementations also has consulting support):

- The Chattanooga Area Regional Transportation Authority in Chattanooga, Tennessee, is deploying a sequence of transit technology initiatives including implementation of an AVL system. This is a smaller agency with a fleet size of fewer than 100 vehicles. The project is championed directly from top management, by the Executive Director and the General Manager. They hired a dedicated project manager who had the title of Technology Manager. His responsibilities include project management for the various transit technology projects and general in-house IT support.
- Hillsborough Area Regional Transit in Tampa Bay, Florida, is a small- to medium-size agency with approximately 300 vehicles. It is deploying its AVL system under the leadership of the General Manager of Operations, with a dedicated project manager structured within the Operations Department to support this and other transit technology projects underway.
- Capital Metropolitan Transportation Authority (CMTA) in Austin, Texas, is a medium-size agency with a fleet of approximately 600 vehicles. The CMTA champion for its AVL system is the Executive Vice President/Chief Operating Officer. It has a range of transit technology projects underway and has established a dedicated Project Management Office, structured under the IT department. A Project Management Officer leads this office and has a supporting staff of five, who share project management responsibility for numerous different transit technology projects. Some smaller projects are assigned a single project manager, whereas responsibility for a large project such as the AVL system is shared by the entire team.

Management Policy on When to Use a Vehicle in Revenue Service

One area that requires policy consideration from management is the criteria on ITS maintenance issues that would warrant preventing a vehicle from being released for revenue service.

- The absence of fully operational onboard AVL system components does not represent the type of safety issue that would inherently disqualify a vehicle for revenue service (e.g., faulty brakes). However, a vehicle without operational AVL does involve some reduction in security, owing to the loss of location tracking capability, in particular in the event of covert alarm activation.
- Vehicles operating without the AVL system operational will pose a complication for dispatchers and supervisors, and the agency will not collect essential data such as APC counts. Also, customers would not receive accustomed amenities such as next stop announcements, and the deficiency would somewhat compromise the accuracy of next arrival predictions for stops.
- For BRT services in particular, the inability for vehicles to offer some of the services that have been put forward to the public as constituting the level of service difference that essentially defines the BRT as distinct will be even more sensitive.
- On the other hand, it is a daily challenge for most transit agencies to have sufficient vehicles available to support the entire scheduled pullout and any criteria that increases the chance that a vehicle would be made unavailable for operation cannot be taken lightly.

Management Role in Fostering Internal Acceptance of Automatic Vehicle Location Data

Once the system is operational one key role for Management is to spearhead the efforts of Planning to work with Operations to establish the validity of the data that the AVL system provided. For key performance measures such as on-time performance and ridership the agency will be familiar with the conventional sources of such data. Even though the new data sources will likely be more comprehensive and consistent than conventional sources, agency staff may resist accepting the new data or question its validity. This will particularly be the case if the new data are substantially different from the conventional data, especially if the new data are less favorable. Management should address the following key aspects to help ensure that the agency effectiveness uses AVL system data so as to fully achieve the potential value of these data.

- Agency personnel needs to accept that the AVL system is reliable, accurate, comprehensive, and consistent, and thus capable of producing more and better data than using conventional data collection techniques.
- There will be much more data continuously available from an AVL system than was available through conventional methods. The agency will need to create the capacity to effectively analyze the AVL system, which may in some cases involve additional staff.
- Beyond the role of Planning to transform a large volume of continuous AVL system data into useful information through its analysis processes, Management needs to establish processes to ensure that this information is distributed on an ongoing basis to staff that need it (e.g., Scheduling, Operations, Maintenance, and Marketing).
- The final link in the chain is for Management to ensure that once useful information is being continuously created and distributed to the right people, there is an expectation that personnel will use the information in a proactive manner to glean value from the AVL system.

OPERATIONS

For both fixed-route and paratransit, operations staff is the most direct and intensive users of a bus AVL system, although not necessarily of the AVL system data. These operations users include operators, supervisors, and dispatchers.

Impacts on Fixed-Route Operations

For fixed route:

- Operators generally use the MDT to request a voice call for communications with dispatch, send and receive text messages with dispatch, and receive route and schedule adherence feedback.
  - The MDT can also automate several functions for which operators are conventionally responsible, thus freeing them up to concentrate on safe driving, schedule adherence, and fare collection. Such automated functions can include next stop announcements, headsign changes at the end of each trip, logging in to the headsign and farebox, and passenger counts.
  - The transition away from open voice channels will be noticeable and important to operators. They will no longer need to cope with the ongoing chatter on an open radio channel, but will need to adapt to the concept of needing to place a Request to Talk and wait briefly rather than being able to speak to dispatch whenever they choose.
  - Another positive impact for operators is available if the system includes a covert alarm and microphone.
- Dispatchers use the AVL software to track the status and locations for all fleet vehicles, including revenue, supervisory, and maintenance personnel.
  - The software is also used to manage voice call requests from the fleet and to support text messaging to vehicles. The transition from open channel voice radio communications to dispatcher-controlled voice calls represents a substantial change. Rather than being able to roam within the dispatch center area listening

to radio traffic and intervening as required, dispatchers using an AVL need to actively monitor the AVL software on an ongoing basis because status message changes onscreen will prompt their actions.
  - The AVL mode of operation represents a significant change for dispatchers from a more conventional approach to dispatching. Instead of needing to remember the details of why a vehicle requires dispatch support, as well as their status and location, dispatchers have immediate access to comprehensive real-time information for the entire fleet, including the prioritization of which vehicles require support or intervention.
  - Where an agency has multiple dispatchers, many of the conventional strategies for dividing fleet operations management between them are supported by AVL software (e.g., dividing the fleet by route or geographical zone).
  - Livermore Amador Valley Transit Authority (LAVTA) in Livermore, California, noted that it has an ongoing challenge training dispatchers to use the AVL system in the intended manner, because there is significant turnover owing to low wages and benefits (they are employees of a private contractor) (J. Rye, LAVTA, personal communication, June 7, 2007). With an AVL system, its dispatcher and supervisor users may require a salary increase in recognition of their new duties and skills.
- The impact for supervisors largely depends on the specific manner in which their vehicles are equipped.
  - If the vehicle is simply equipped with an MDT, the effect is largely limited to the change in operation for the vehicle radio from open channel to dispatch-controlled voice calls. Supervisors are also often equipped with a portable radio that can support monitoring of dispatcher and operator voice calls and open channel communications with other supervisors and/or dispatch.
  - Some systems provide supervisors with an “enhanced” MDT that supports limited dispatch capabilities, including the ability to set up voice calls with operators and in some instances even to receive status and schedule adherence data for selected vehicles. However, the extent to which MDTs can support such concepts tend to be fairly constrained by the limited display screen and by the limited radio system data capacity.
  - An increasingly common approach equips supervisors with a ruggedized laptop computer mounted in the vehicle that runs the AVL software and offers substantially similar capabilities to those available for dispatchers (typically with data communications over leased cellular data service):
    - △ Attempts to provide such onboard capabilities for supervisors have become more widespread in the past few years because of the increasing maturity and cost-effectiveness of the enabling technologies such as ruggedized laptops, leased cellular data accounts, and Citrix servers (i.e., for remote application access).
    - △ In many cases, the intent is simply to provide enhanced information that enables supervisors to work more effectively and also spend more time in the field, because they do not need to be in office to complete paperwork.
    - △ With such technologies in place to provide supervisors with all the capabilities of a dispatcher, it is conceivable that some agencies could evolve toward a “mobile dispatch,” with the dispatcher role merged into that of the supervisor, at least during periods of lower intensity operation.
  - Either of the latter two approaches offers a significantly greater level of information availability to supervisors. At a minimum, supervisors are empowered with additional real-time information that allows them to take an increasingly proactive approach. Consequently, there is less need to simply react to requests from dispatch and operators. There is the opportunity to distribute a certain amount of dispatcher responsibility out to supervisors who would effectively be operating as “mobile dispatchers.”

Impacts on Paratransit Operations

In paratransit, the impacts are similar yet distinct:

- For operators, the MDT provides the same voice call request and text messaging capability as it does for fixed-route operators, but it does not need to provide schedule adherence feedback. The strongest benefits for paratransit operators come from the system providing routing support that no longer requires the operator to deal with paper maps and trip manifests. Some MDTs also provide a navigation function, with a map indicating the current location and perhaps also the location of the upcoming destination (possibly including turn-by-turn route guidance). Also, a paratransit MDT provides an “electronic manifest”:
  - The list of daily pickups and drop-offs for the run are automatically downloaded to the MDT once the operator has logged on; the download will include all the associated information commonly found on a conventional paper manifest (e.g., name, address, type/fare codes, and comments).
  - When there are additions, cancellations, or changes to the manifest throughout the day, these revisions are seamlessly updated in the MDT.
  - As trip events are completed during the run, the operator presses an MDT button that transmits time- and location-stamped data to dispatch. Commonly, the operator presses an “arrive” button when the vehicle first gets to the location and presses a “perform” button as the vehicle is about to depart that location.

- Common industry practice is to continue giving the operator a paper manifest at the beginning of the run as a contingency. If the MDT or data communications were to fail during the run, the operator could use the paper manifest as a backup to continue providing service. Dispatch would need to inform the operator over the voice radio on how to mark up the manifest for upcoming trips to reflect changes since the start of the run, and the operator would need to mark trip completion data on the manifest as well. In cases where the MDT remains operational but data communications are lost, a common practice is for operators to continue entering trip completion data in the MDT while at the same time marking up the manifest. If data communications return, the MDT can "catch up" with receiving manifest updates and sending completed trip data. If, on the other hand, data communications do not return during the run, the agency can use the marked-up manifest to enter the trip completion data directly into the paratransit schedule/dispatch software.

- For paratransit central system operations, the impact comes from incorporating AVL capabilities into scheduling and dispatching software, which generally assist with enhancing real-time aspects of operation:
  - Reservationists could schedule same-day trip bookings, because these can be made using information on real-time vehicle locations, capacity, and schedule status that allow for more cost-effective "along the way" vehicle assignments.
  - Similar to the impact with fixed route, dispatchers can generally operate with enhanced real-time situational awareness of the fleet location and status and avoid the stress of open radio channel operation. An aspect specific to paratransit allows improved control over "no shows," because the time since the vehicle actually arrived at the location is known (i.e., if there is a policy that a "no show" cannot be requested until the vehicle has been on location for at least *X* minutes, the agency can apply this policy systematically).
- Paratransit dispatchers can be equipped with a similar range of onboard systems options to those discussed previously for fixed route, with similar general effects. One extra feature sometimes made available in an enhanced MDT for a paratransit supervisor is the option to select a specific manifest for monitoring in real time.

Impacts on Operator Login

An impact common to both fixed-route and paratransit operations is the automated operator/run login using the MDT, and the implications of this for operators, timekeeping, payroll, and human resources. Conventionally, operator timekeeping and payroll are based on the sign-in and sign-off for the run with dispatchers before boarding the vehicle. With an AVL system, there is an additional source of data because the actual times of MDT login, pull-out, pull-in, and arrival at on-street relief points are known. Agencies can use these data as a cross-check against sign-in and sign-out times, or could conceivably even as a replacement of sign-in and sign-out as the basis for timekeeping.

With the new AVL system CMTA in Austin, Texas, is currently implementing, MDTs are being enabled for badge-only login to maximize the accuracy of operator login to the AVL system. Under this approach, the operator will login by using a machine-readable identification badge (e.g., magnetic stripe card or smart card) near an onboard reader, rather than needing to enter their identification number into the MDT manually. The MDT will transmit the operator identification to the central system, which will retrieve and send back the current run assignment; this will eliminate the need for the operator to manually enter any data to correctly login to the MDT. One important benefit for operations will be the reduced incidence of the operator entering an incorrect operator and/or run identification into the MDT, which is essential to enable the effective use of MDT login data for timekeeping purposes.

MAINTENANCE

Maintenance Skills and Practices

Maintenance staff will need to extend their capabilities to support the new types of onboard and field equipment that are implemented as part of the AVL system. Maintenance staff who previously supported onboard electronic equipment (e.g., radio, farebox, and headsign) is likely candidates to extend their skills to support the new equipment (e.g., VLU, operator interface, announcement system, APC, and DMS).

For the DMS located at stops, maintenance can only be performed with a road call. Even with the onboard equipment, it is so essential to effective operations that a road call may be preferable to the vehicle operating the rest of its block with its AVL system out of service. These factors add a new dimension to established garage maintenance operations and suggest the potential need for some additional mobile maintenance capabilities, which would involve challenges for the additional required staffing and non-revenue vehicles. For example, with the BRT system operated at Alameda–Contra Costa Transit District (AC Transit) in Oakland, California, the onboard AVL equipment is considered essential to maintaining the distinct quality of service that helps define BRT and ensuring that supervisors will replace that faulty equipment if possible at the end-of-trip layover.

Spare Parts Management

Agencies that operate from multiple operating bases have a particular challenge in managing spare parts inventories. Because it is essential to minimize downtime when an onboard component requires replacement, it is necessary that agencies have some spares available at each location. Because the size of the spares pool at each location may not be large, the agencies must have an efficient system for distributing replacement spares in small quantities to those locations as they are used. In most cases agencies use a central maintenance facility that provides a centralized spares pool and handles the procurement of spares. There is an additional challenge when an operating location is for contracted service, because the agency and the contractor typically want to avoid having many of these spares (i.e., the property of the agency rather than the contractor) stored at the contractor site.

For its suburban paratransit operation, PACE in Chicago, Illinois, has equipped vehicles operating out of several widely dispersed contractor locations with an AVL system, each with roughly 30 to 50 vehicles. The initial approach that evolved for spares distribution was to provide a single spare for each site. Whenever that spare was installed in a vehicle (known because the replaced component would be sent in from the contractor site for repair or replacement), PACE would at that time send a replacement spare.

Use of Diagnostics Data

Bus AVL systems can enable the collection of comprehensive maintenance data from fleet vehicles and provide appropriate maintenance data in real time. As part of the standard vehicle configuration as purchased, onboard electronic control modules for major components are often equipped to communicate key data (e.g., temperature, pressure, and malfunctions) with each other over an onboard SAE J1708 communications network. Agencies can configure the onboard VLU to monitor messages on the J1708 network, recording selected messages when the values pass configurable thresholds. These thresholds can involve not only the value of a monitored parameter (e.g., engine oil temperature exceeding a set level), but also when the threshold is exceeded with a certain frequency or duration. This type of integration—using the AVL system to help with drivetrain monitoring—is not yet a commonly deployed feature of bus AVL systems. In the responses to survey Question 6, only about 9% indicated that this feature was included in their AVL system.

Agencies would upload the recorded data as part of the overall bulk data transfer process when the vehicle returns to its garage (together with other key data such as odometer and operating hours), and transfer the data to a maintenance management system for use in scheduled required maintenance, proactively anticipating maintenance actions that could help avoid expensive and disruptive in-service breakdowns.

The impact on maintenance operations is that there is a need to create procedures to systematically review and take action on the increased amount of daily maintenance data. This can involve a shift in emphasis from maintenance departments focusing primarily on scheduled preventative maintenance and repairs to undertaking proactive maintenance with vehicles that can serve to minimize in-service breakdowns. As with other aspects of integrating AVL systems with maintenance operations, this would involve new capabilities for maintenance staff.

As was learned during AVL system implementation at KCATA, it is important that the VLU apply filtering as to which of the data received from the drivetrain monitoring system is actually recorded. The drivetrain monitoring produces a large amount of status data, much of which is either repetitive or not of critical interest to Maintenance. The reports initially generated during the implementation with these data were for this reason not considered useful by Maintenance. In response to this concern, the AVL system vendor implemented filtering so that the VLU would only record data that exceeded set thresholds, thus avoiding recording repetitive data.

Future Evolution of Maintenance Using Automatic Vehicle Location

As part of this overall approach, some of the maintenance data recorded in the VLU can be flagged as warranting real-time transmission to the central system over the mobile data communications system. The criteria to warrant sending maintenance data in real time is typically that having immediate notification of the condition would allow the agency to trigger a proactive maintenance action that could prevent more serious and expensive maintenance (e.g., ensuring that an overheating engine is shut down).

This additional capability would require a further shift in the approach to maintenance management, with methods needed to provide immediate notification when such a maintenance alarm is received (e.g., AVL system triggers an e-mail to the mobile personal device of a maintenance supervisor). The notified maintenance supervisor could then speak with a dispatcher (or check an AVL workstation provided in Maintenance) to communicate instructions to the operator. If on-street maintenance support is required, Maintenance would be able to see the locations of both the affected vehicle and maintenance support vehicles in the vicinity.

The specific way that maintenance staff would interact with the maintenance monitoring capabilities of the AVL system will depend on whether the AVL system is interfaced with maintenance management software. Without maintenance management software, maintenance staff would interact directly with the AVL system (e.g., view dispatch screen, receive reports, or e-mail notifications). With maintenance management software, maintenance-related data would be transferred from the AVL system by means of the interface, and maintenance staff would tend to interact only with the maintenance management software.

CUSTOMER SERVICE

Agencies can provide customer service staff with access to both real-time and historical AVL system data, which can help customer service agents believe that they are empowered to provide more useful assistance to customers and investigate important issues:

- Real-time data on vehicle status can help customer service respond to the common "where's my bus" call, making available current information on both the locations and schedule adherence status for vehicles approaching a stop of interest. In some systems, the AVL system data available may extend to arrival time predictions for upcoming stops.
- Historical data can help customer service agents address comments or complaints about service that has already been completed. For example, if a customer complained that a bus passed them by at a certain time or that they waited a certain time with no bus appearing, agencies could review the historical data (i.e., using the "playback" feature typically available in an AVL system) to assess the reasonableness of the complaint.

In AVL systems that incorporate real-time next arrival predictions on DMS at stops, as well as perhaps other methods to disseminate real-time passenger information such as an IVR telephone system or through the agency website, there is heightened awareness and visibility to the general public and the media. This can result in a new type of call for customer service representatives, related to concerns about the perceived level of accuracy of the real-time passenger information.

The KCATA experience while implementing its real-time passenger information DMS for the MAX BRT, as part of its overall AVL system implementation, was that the new policy customer service agents noting details for this type of feedback and forwarding it to the agency staff most involved in deploying the system helped to improve the real-time passenger information. There were several instances where opportunities to improve the calibration of the real-time passenger information system and run schedule data were noted through this type of feedback from customers (i.e., this feedback supplemented the acceptance testing activities undertaken by the systems integrator and agency implementation team).

If an agency implements an IVR telephone information system to leverage AVL system data to provide automated systems to straightforward customer questions, this can enrich the job experience for dedicated customer service agents (i.e., job satisfaction can increase as the calls they handle shift from routine calls to the more challenging customer questions that go beyond what the IVR can address and rely on the in-depth system expertise of the agent). The transit agency might be able to handle growth in its service without needing to increase the customer service staff, although it might be important to ensure that the customer service staff has the required level of expertise.

SECURITY

The primary effect of an AVL system on security staff is that enhanced information from dispatch will assist them as they approach an incident involving an in-service vehicle (i.e., to find the vehicle quickly). Dispatch will be able to immediately direct Security to the location of the vehicle involved and inform them whether the operator has signaled an emergency situation using the covert alarm. Also, covert audio monitoring may provide a better indication of the specific situation involved and allow security to request additional appropriate support from other public safety services more quickly.

INFORMATION TECHNOLOGY

IT staff will not be direct users of the AVL system, but will have a critical role in maintaining the system hardware and software and in maintaining the underlying agency networking and communications infrastructure over which the system operates. Many different business units will use the AVL system, and they will all rely on IT to keep the system operating reliably and effectively. As with other agency systems, IT provides a support function. Agency business units that use the AVL system will need to take the lead in defining the functional, performance, and availability requirements, and in ensuring that IT has suitable resources to support these requirements.

For matters such as maintaining workstations, servers, and the network, the effect of AVL system implementation can be a substantial increase in the scope and scale of the support IT staff must provide. Some elements commonly introduced with an AVL system may involve new types of technology and network integration. In particular, this may be the case with bulk data transfer and mobile data communications. Bulk data transfer may use WLAN technology and require the management of the associated network security issues. The agency will need to integrate the mobile data communications system with the network, although it most likely operated the prior voice radio communications as a stand-alone system with which IT may have little involvement.

IT staff will need to become knowledgeable with these new technologies and how they are used; IT will need to adapt its support procedures accordingly. Because an AVL system involves such a broad range of users from numerous departments, to provide support to an AVL system will require that IT understand many new business processes before implementation (e.g., Operations). IT's increased and expanding understanding of operations throughout the organization gained through supporting an AVL system will likely prove useful in enhancing IT's ability to support other future initiatives that will be deployed throughout the agency.

CMTA's (Austin, Texas) approach to this issue has been to assign during the implementation phase an IT Applications Administrator to lead IT support for the central software and data. This person has been working closely with the project management team on reviewing the system's design and developing the system configuration data (i.e., all the data that needs to be entered into the software to configure it for use at CMTA), effectively serving as the IT liaison to the project management team and representatives of other business units participating in the implementation process.

The overall effects often include the need to hire additional IT staff, as well as to provide extensive training for existing and new staff. Some staff may require a broader range of skills, and the agency may require 24-hour-a-day support to ensure sufficient AVL system availability. These factors may require an adjustment in pay scales for some IT staff. Sufficient IT resources are needed to enable their effective support for the AVL system together with the many other systems initiatives that already exist at the agency.

LAVTA in Livermore, California, reports that before its AVL system implementation the organization did not have dedicated IT staff. One planner with a technical background supported IT on a part-time basis. After AVL system acquisition LAVTA added one full-time position to provide general IT network and desktop support and to support the AVL system and Trapeze fixed-route scheduling software. However, they found that one IT position did not appear to be enough to provide both types of support, while keeping these systems working well and producing high-quality data. LAVTA has found it relatively easy to find general (network and desktop) IT support. However, they often find that these IT generalists appear unsuited and disinterested regarding the applications support for the AVL and scheduling systems (lacking background and interest in public transit). LAVTA is trying to hire a dedicated support specialist for these applications, but has found that persons with the needed aptitude, experience, and interest are uncommon (this should gradually improve as AVL systems become increasingly prevalent in the transit industry). They suspect that they may need to develop this capability in-house (J. Rye, LAVTA, personal communication, June 7, 2007).

Similar experience with the lack of interest and/or support from IT departments has led some agencies to set up separate ITS business units with ITS specialists, or to at least establish specialized ITS staff within existing business units. The focus of these specialists can initially be on the planning, deployment and acceptance of the ITS system, and can evolve to providing ongoing support for the use of the ITS system and planning for the system enhancements or replacement that will eventually be warranted.

PLANNING

An AVL system can provide additional data for use by planning staff in documenting revenue, ridership, and performance, as well as in assessing opportunities to enhance service.

- APC will provide a new source of data for ridership counts, and many APC systems can also provide data on running and dwell times (i.e., by recording location- and time-stamped events for door open and door close).
  - Planning staff will need to assess how to best interpret the raw APC data and the "post-processed" APC data refined to identify and address erroneous data, as well as how to combine APC data with conventional sources of ridership data such as farebox revenue and "ridecheck" manual counts.
  - The data need to be effectively used both for internal purposes and for NTD reporting if desired. If APC is installed on only a subset of the fleet, Planning may need to be involved in determining a trip sampling plan that would interact with Operations regarding the vehicle block assignments. Most agencies are still exploring how APC data can best be used to meet NTD requirements.
  - Planning will also need to interact with Maintenance to notify them of APC equipment that may be malfunctioning, based on the analysis of the raw data.
- Planning is commonly responsible for the periodic processes to update the schedule (i.e., routes, trips, blocks, and runs). As an extension of this established role, planning staff typically are involved in supporting the way schedule data are used as a key input to an AVL system:
  - Planning may take a lead role in exporting a version of the schedule data into a format that can be provided as input data to the AVL system. Because the schedule data needs to be distributed to the entire fleet (e.g., using the bulk data transfer system) before the new schedule is in effect, it may be necessary to adjust procedures and timetables to complete schedule preparation a few weeks earlier to allow enough time for this distribution. Also, when planners are initially configuring these data for use in supporting the AVL system as part of the deployment, it is common for them to identify some data refinement needs for using these data with the new system (e.g., geographic locations for timepoints and stops may need to become more accurate).
  - The schedule data distributed to the fleet is used by onboard systems to track the vehicle against the current run, primarily to enable route and schedule adherence monitoring. These data are sometimes also used to trigger other onboard system actions based on run progress. This can include defining trigger locations for next stop announcements, signaling the end of each trip to headsign and farebox,

and generating TSP requests. Additional data are associated with several of these functions (e.g., next stop announcement content, headsign destination message, and farebox fareset). Planning often ends up being involved in supporting the incorporation of all this additional information into the schedule file for onboard systems use.

- Planning may use running and dwell time data from the APC system and a more-detailed assessment of playback data from the AVL system to assist in its periodic schedule adjustments process. There are potential opportunities to use the large range of available data to investigate the potential effects of various factors on running and dwell time, to obtain the variations in running times, and to assist in developing optimal schedules (e.g., time of day, day of week, month of year, operator experience, and passenger boarding volumes). In implementing the KCATA AVL system, it was discovered that using the AVL data to improve the accuracy of the schedules was also important in enhancing the accuracy of the information displayed on the stop DMS for its MAX BRT, because the accuracy of the next arrival predictions in this AVL system largely depends on the accuracy of the run schedule data.
- Analysis of dwell time at intersections (which may be available from the AVL/APC data depending on its level of refinement) can also be used to help target intersections and corridors for TSP deployment.
- There may be requests to share historical data with other regional transportation agencies or planning organizations, which Planning might be responsible for coordinating. For example, traffic management departments may be interested in the accumulated historical data for transit running speeds at various times as an indicator for general traffic speeds. As discussed in the literature review, King County Metro in Seattle, Washington, has been working with University of Washington researchers and the Washington State DOT on using data from the King County Metro AVL system for estimating general traffic speeds in real time, an approach generally referred to as using the transit vehicles to serve as "traffic probes."
- Planning staff that make use of data from the AVL system may require training on how to use the AVL system features to generate standard reports and how to create customized ad hoc reports. Owing to the need for specialized training, responsibility for working with AVL system data may need to be focused on selected Planning staff (i.e., as opposed to needing to provide the training to all Planning staff).
- Requirements for generating the standard reports and ad hoc reports in the AVL system that Planning will need should be incorporated into the RFP specification requirements, so Planning should be involved in the system development process before the RFP is even issued. If this opportunity is not used, Planning will likely have reporting needs that are not supported by the specification, meaning that they will either not be available in the completed system or that the agency will need to pay extra to the systems integrator for the reporting additions.

REVENUE

If the onboard systems are interfaced with the farebox one effect of an AVL system for revenue is a likely improvement in the quality of farebox revenue data.

- With a single onboard login, the login run is more likely to be correct (i.e., with multiple logins there are more opportunities for operator error).
- The VLU can signal the farebox at the end of each trip rather than needing to rely on the operator for this function; the farebox uses this signal to segment the revenue data by trip.
- The accuracy of farebox data can be further enhanced if operators are relieved from entering the fareset, provided this is included with the onboard run data used by the AVL onboard system.
- Farebox revenue data can be further enhanced by location tagging.
- Farebox alarms can be monitored by the VLU and sent in real time to dispatch so that supervisors can be alerted to the problem.

MARKETING

The primary impact of introducing an AVL system to the marketing staff is that they will need to introduce and promote the new system to the public. This is an important task because the AVL system is a substantial investment and it will be critical that the public are informed of the changes in how they will experience the system on a daily basis. It is also important that the public and media are informed once the agency has begun to experience benefits from using the AVL system.

Assuming that the AVL system is a key project within an overall broader technology development program, marketing staff have a key role in promoting a positive response to the AVL system so that the public will consider this and other future technology investments worthwhile. The role of Marketing will be particularly important if the AVL system includes real-time passenger information, because such system elements are highly visible to the public and media. It is important for Marketing staff to have training in the AVL system to understand what it can and cannot do.

Marketing staff may also work with the Planning department to use APC data to assist with marketing efforts for the transit service in general. The APC data provide comprehensive data for all stops on which the APC-equipped vehicles operate, including for boarding and alighting volumes at the trip and stop level. The agency can use these data to improve ridership projections and to measure the ridership effects of service adjustments at a very detailed level, including the ability to estimate ridership between particular origins and destinations. APC data can also be used to help prioritize the deployment of customer amenities (e.g., shelters).

TRAINING AND HUMAN RESOURCES

Training and Human Resources have a critical role when a major systems initiative such as a bus AVL system is introduced. Because such a large number of staff and departments will require training in how to effectively use the system, this training will be a major source of required training on an ongoing basis. When the system is being deployed, Training's primary role will be in coordinating the training the systems' integrator is providing under their contract.

Some deployment contracts involve the systems integrator providing a "train the trainer" approach for some positions with a large number of staff such as operators. Under this approach, agency staff will need to complete much of the training in-house for these staff positions. Once the system is in revenue service, training for new employees and periodic refresher training for staff in various departments will become an ongoing task.

As the various business units continue to adapt their practices to gain increasing value from the AVL system and the data it provides, training needs to be continuously adapted to incorporate these innovations. Another useful source of training for management can be site visits and other information sharing with peer agencies that also use an AVL system, both to provide and receive insights into innovative practices and data uses. Transit staff has also used the U.S.DOT "Peer to Peer" program to support site visits or assistance from peers at agencies that already have experience with AVL systems.

For example, the ACCESS paratransit operation of King County Metro indicates that they originally planned for classroom training for drivers, but realized they were not able to take enough drivers off the road to support direct driver training from the vendor in the larger-class sizes required. They instead used a "train the trainer" approach, with brief individual classroom training followed by 4 to 8 h of behind-the-wheel training. Contracted service operators have also incorporated MDT training into their driver training programs.

Another method commonly used by transit agencies is the use of Standard Operating Procedures to facilitate training and enable consistency. For its implementation of the Valley Metro AVL system, Phoenix Transit extensively revised its previous Standard Operating Procedures for dispatchers and uses these as a training and reference tool.

CHAPTER SIX

BENEFITS AND COSTS

This section discusses the benefits and costs involved with the implementation of a bus AVL system. These are important in gaining approval to implement a system, but the actual benefits and operating costs experienced, relative to the situation before the system was implemented (i.e., as gathered through a system evaluation), will have an impact on whether the system implementation is considered a success.

Industry experience has been that agency operating costs are not typically reduced through implementing an AVL system, and that agencies may need additional maintenance, IT, and planning resources to achieve full value from the system. The considerable value in implementing an AVL system arises from its ability to improve service and to gather more comprehensive and accurate data that can enhance scheduling, service design, and operations. An AVL system can also support new passenger amenities (e.g., next stop announcements and next arrival predictions at stops) and carry future increases in the scale of operations with the same staff or reduced staff increases, which can be considered an operating cost savings in the sense of costs avoided.

For example, the Greater Bridgeport Transit Authority (GBTA) in Bridgeport, Connecticut, recently awarded a contract for an AVL system. GBTA did not justify this initiative as a cost savings measure, but rather stressed the AVL system as a strategic investment through which the agency would achieve ongoing value in various areas. The GBTA AVL system will serve as a pilot for potential statewide deployment in Connecticut. Although state interest has somewhat waned, with this focus on value rather than cost savings GBTA was able to nonetheless maintain support for this initiative.

The industry is in the midst of a gradual shift toward assessing by the public, transit agencies, government funding sources, and the media AVL system features as an essential element of a quality "transit product," analogous to the evolution toward certain other transit features becoming increasingly expected as the norm (e.g., air conditioning and shelters at high-volume stops). The essence of this shift is that increasingly over time it becomes necessary to justify why an agency is not including a feature rather than justifying whether they should. The industry does not seem to yet be at such a "tipping point," and it is not certain that this shift will occur, but it is becoming more common for agencies to be considering an AVL system in part because one has been implemented successfully by some of the agencies considered its peers. The challenge is to avoid believing that an AVL system will be a "magic bullet" that can accomplish far more than is realistic (or justifying the system on such a basis), because this creates unrealistic expectations for the initiative.

The capital costs will be quite visible, as will be the operating costs, but the agency may need to make some effort to help make the benefits as well known and understood (especially those benefits that are more qualitative in nature). There is some risk that if the benefits are not made sufficiently visible to management and those that provide agency operating funds, resistance could arise to ongoing funding for operating costs. This effort to assess benefits could also have the positive effect of identifying further actions that agencies can take to increase the benefits being achieved from the system (e.g., changing how the system is used or enhancing the system further).

BENEFITS

Benefits can be categorized as quantitative or qualitative. Some benefits can be quantified in monetary terms or otherwise (at least approximately), but there are often also qualitative benefits that are still important to consider. In most cases a benefit can involve both categories, with a more broadly stated qualitative benefit complemented by some specific aspects of a quantifiable benefit. In many AVL system implementations, the implementing agency did not systematically evaluate aspects of benefits that might have been quantifiable as they did not see a need to undertake the additional evaluation.

Some expected benefits of a bus AVL system for fixed-route operations follow:

- AVL software provides improved situational awareness and additional voice communications management capabilities for dispatchers, expanding the size of the fleet that can be handled by each dispatcher.
- Schedule adherence feedback to dispatch, operators, and supervisors helps to maximize on-time performance and reliability.
- Dispatchers and supervisors can be proactive in addressing operational issues, including more timely and effective reaction to service disruptions.
- Text messaging can improve dispatch efficiency and provide clearer messages in distributing information to operators.

- Covert alarm monitoring supports the ability of operators to quickly inform dispatch about an onboard emergency and for dispatch to immediately know the vehicle location to send assistance.
- Single point for operator login to all onboard equipment reduces the potential for inaccurate login, maximizing the accuracy of schedule adherence, headsigns, and farebox data.
- Automated next stop announcements provide consistent announcements for passengers, reduce operator workload so they can focus on safe vehicle operation, and help address the requirements of the ADA.
- APC equipment allows for the cost-effective collection of comprehensive passenger boarding and alighting data with consistent reliability, relative to the use of human ridecheckers.
- The system can provide real-time next bus predictions to customers both pre-trip and enroute, which can help increase ridership by reducing customer anxiety, enhancing perceived reliability, and generally presenting a more "modern" image (in particular among "choice" riders).
- More comprehensive historical data collection and incident reporting allows more effective and detailed analysis (e.g., for Planning to use historical schedule adherence data to develop schedule adjustments).

The ITS JPO AVL Systems Cross-Cutting Study from 2000, discussed in the literature review for this synthesis (see chapter two), provides the following detailed list of qualitative benefits gathered from the six AVL systems that formed the basis for the report.

- Operations
  - Improved schedule adherence,
  - Improved transfer coordination,
  - Improved ability of dispatchers to control bus operations,
  - Facilitated on-street service adjustments,
  - Increased accuracy in schedule adherence monitoring and reporting,
  - Assisted operations during snowstorms and detours caused by accidents or roadway closings,
  - Effectively tracked off-route buses,
  - Effectively tracked paratransit vehicles and drivers,
  - Eliminated need for additional road supervisors,
  - Reduced manual data entry,
  - Monitored driver performance, and
  - Received fewer complaints from operators.
- Communications
  - Reduced voice radio traffic,
  - Established priority of operator calls,
  - Prevented radio calls from being lost, and
  - Improved communications between supervisors, dispatchers, and operators.
- Passenger Information
  - Provided capability to inform passengers of predicted bus arrival times,
  - Helped meet ADA requirements by using AVL data to provide stop annunciation,
  - Increased number of customer information calls answered, and
  - Eliminated need to add customer information operators.
- Customer Relations
  - Received fewer customer complaints,
  - Used playback function in investigating customer complaints,
  - Used AVL data to substantiate agency's liability position, and
  - Improved image of agency.
- Scheduling and Planning
  - Provided more complete and more accurate data for Scheduling and Planning,
  - Expected to ultimately reduce schedule preparation time and staff,
  - Aided in effective bus stop placement,
  - Generated more accurate ridership counts with APCs, and
  - Expected to improve bus productivity.
- Safety and Security
  - Used AVL-recorded events to solve fare evasion and security problems,
  - Reduced the number of on-bus incidents by use of surveillance cameras,
  - Provided more accurate location information for faster response,
  - Foiled several criminal acts on buses with quick response, and
  - Enhanced drivers' sense of safety.

Expected benefits of a bus AVL system for paratransit operations include:

- Electronic manifests and trip completion data reduce operator workload and provide more accurate and consistent data.
- Real-time fleet location data further improve the ability of scheduling software to enhance vehicle productivity and accomplish meets with fixed-route service.
- Onboard navigation assistance aids operators in keeping on schedule with their manifests, in particular with newer operators who are less familiar with local streets.

The literature review reported in this synthesis (see chapter two) provided several examples from research studies of estimates for quantitative benefits.

- For the TriMet AVL system (Portland, Oregon):
  - Improved availability of real-time information for dispatchers could reduce running times by an average of 1.45 min/trip and reduce average passenger waiting time at the stop by 0.11 min.

  - Depending on the assumptions regarding reduced wait times and reduced wait time uncertainty, the number of annual transit trips with Transit Tracker information by means of the Internet needed for positive net benefits could range from approximately 200,000 to 900,000.
- For the COTA AVL system (Columbus, Ohio), with changes in dispatcher workflow the observed overall effect was of saving nearly 3 h in the time required for daily work. It was projected that a fleet size increase of up to 10% could be accommodated with the current complement of dispatchers.
- For the Delaware First State AVL system, roughly $2.3 million in annual benefits were estimated as reasonably attributed to the implementation of the system.

COSTS

Agencies can categorize costs as capital or operating. Capital costs are defined here as those costs incurred once during the implementation of the project, whereas operating costs are the ongoing (in many cases recurring) costs of keeping the system in effective operation once it is in revenue service.

Agencies should take care to avoid attributing costs solely to the AVL system if they need to be undertaken for other reasons. Some examples include:

- If the agency is planning to integrate the AVL system onboard with fareboxes, the cost of new fareboxes or enhancements and the cost of their integration should be considered part of the fareboxes project rather than the AVL project.
- Ongoing costs for new staff should not be attributed solely to the AVL system if some of this staffing would have been needed for other reasons.
- Costs associated with voice radio communications (e.g., monthly lease charges for tower space or leased lines to towers) should not be attributed to the AVL system because voice communications is a conventional dispatch capability needed regardless of whether AVL is implemented. On the other hand, costs to implement or enhance mobile data communications to support the AVL system, or to control access to voice communications through the AVL system, should be attributed to the AVL system.

Capital costs include the various one-time costs undertaken by the agency that are reasonably attributable to achieving the operational system ready for revenue service. This includes the costs for what is procured from the systems integrator and the additional agency costs attributable to the system.

Costs for purchases from the systems integrator typically include:

- Onboard equipment, workstations and server hardware, and software (including software licenses and customization);
- Mobile data communications system enhancements;
- Installation (including the potential purchase after the AVL system is in place of new or replacement vehicles with onboard equipment installed during the vehicle manufacturing process);
- Integration, training, and documentation;
- Project management, design review, and acceptance testing; and
- Warranty and an initial supply of spare components.

Capital costs for an AVL system vary from different agency implementations owing to a variety of factors. Some of these factors relate to the scope and scale of the system.

- The cost of the central system remains relatively similar between implementations, with the main variables being the extent of computer hardware and network integration, the number of software users to be licensed, the degree to which software customization is needed, and the scale of coverage needed for bulk data transfer WLAN facilities.
- The cost of the onboard part of the system is the greatest variable:
  - Although it depends partly on the specific equipment and existing components integration required, the primary variable is simply the number of vehicles that will be equipped.
  - Another variable is the diversity of vehicle types in the fleet, because different vehicle types mean that more installation designs are needed, and installation crews must be trained on installation details for each different vehicle type.
  - Yet another factor is any specific installation requirements of the contract. Certain requirements sometimes incorporated to decrease the time required for installations (e.g., installation on several vehicles in parallel), thus reducing the overall duration of the implementation schedule, or to reduce the impact of installation activity on agency operations (e.g., restricting installations to nights or weekends) can involve additional costs for the systems integrator that will be built into the system cost.

Some additional factors can lead to cost variations even for systems of similar cost and complexity, and are more difficult to explain or predict. These usually involve the systems integrator's overall competitive situation at the time of the procurement. In other words, if the proposers perceive that there will be other proposers and similar procurements available in the near future, more competitive pricing could result.

TABLE 34
RECENT AGENCY CONTRACT AWARDS

Agency	Vendor	Year	Fleet Size	Award
Island Explorer (Bar Harbor, ME)	Avail	2001	17	$801,385
Grand River Transit (Waterloo Region, ON)	INIT	2005	34	$2,683,229
Coordinated Transit System (Lake Tahoe, CA)	Orbital	2002	47	$3,600,000
CityBus (Culver City, CA)	Orbital	2005	55	$3,500,000
York Region Transit (Toronto, ON)	INIT	2004	77	$8,695,652
Intercity Transit (Olympia, WA)	Orbital	2005	85	$4,400,000
StarTran (Lincoln, NE)	Digital recorders	2007	93	$1,400,000
RTC (Reno, NV)	Siemens	2002	122	$4,750,000
VOTRAN (Daytona Beach, FL)	Avail	2005	153	$3,812,245
C-Tran (Vancouver, WA)	INIT	2004	165	$3,600,000
Nashville MTA (Nashville, TN)	Orbital	2007	224	$7,300,000
Long Beach Transit (Long Beach, CA)	Siemens	2003	228	$6,500,000
HART (Tampa Bay, FL)	Orbital	2006	297	$9,281,981
Foothill Transit (West Covina, CA)	Orbital	2006	300	$11,700,000
KCATA (Kansas City, MO)	Siemens	2003	356	$6,630,807
Pierce Transit (Tacoma, WA)	Orbital	2007	391	$6,200,000
Bee-Line (Westchester Co)	Orbital	2006	410	$9,700,000
SEPTA Customized Community Transportation (Philadelphia, PA)	Orbital	2007	500	$17,800,000
San Diego Transit, North County Transit District (San Diego, CA)	Orbital	2004	515	$8,400,000
CMTA (Austin, TX)	Orbital	2006	599	$12,141,865
Valley Metro (Phoenix, AZ)	Orbital	2002	740	$14,800,000
TransLink (Vancouver, BC)	INIT	2006	1,296	$30,434,783
Metro Transit (Houston, TX)	INIT	2003	1,315	$20,000,000
NYC MTA paratransit (New York, NY)	INIT	2006	1,329	$16,000,000
King County Metro (Seattle, WA)	INIT	2007	1,449	$25,000,000
WMATA (Washington, DC)	Orbital	2001	1,700	$8,500,000
CTA (Chicago, IL)	Clever devices	2007	1,900	$24,000,000

RTC = Regional Transportation Commission; MTA = Metropolitan Transit Authority; HART = Hillsborough Area Regional Transit; SEPTA = Southeastern Pennsylvania Transportation Authority; NYC MTA = New York City Metropolitan Transportation Authority; WMATA = Washington Metropolitan Area Transit Authority; CTA = Chicago Transit Authority.

Table 34 summarizes the systems integrator contract award portion of the capital costs for some recent bus AVL deployments, sorted in ascending order of the deployed fleet size. These data include 27 different recent contract awards in the United States and Canada, dating from 2001 to 2007, and involving purchases from most of the established major systems integrators for bus AVL systems. Although these systems are generally of a similar nature, there is some variation in the specific scope of the system (i.e., subsystems included) and other aspects that affect cost such as whether the contract included any communications system enhancements. This is not an exhaustive listing of recent contract awards, but covers a broad range of fleet size.

Figure 5 presents these same data in the form of a chart. The chart seems to suggest that a linear model could be useful for how contract award value increases with fleet size, at least for the fleet sizes less than 750 vehicles where most of the data lies. The calculated line of best fit for these data suggests the following equation:

$$\text{Contract Award} = \$17{,}577(\text{Fleet Size}) + \$2{,}506{,}759 \ (\text{with an } R^2 = 0.677)$$

The formula should be used only as a rough approximation of expected capital costs for any given project, owing to the

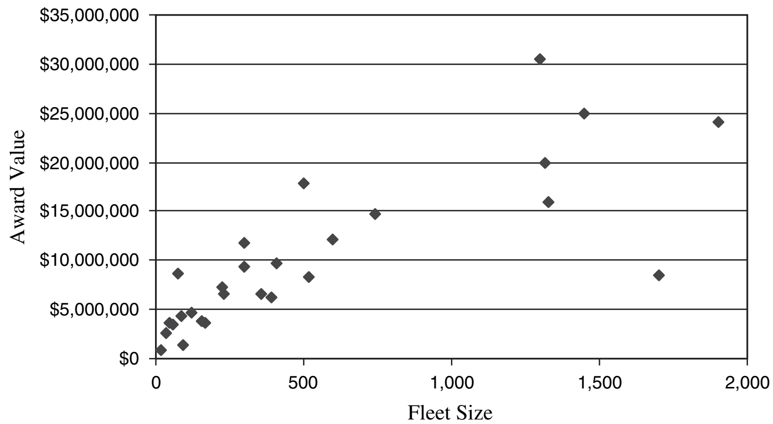

FIGURE 5 Recent contract award values by fleet size.

limited sample size and the numerous specific factors affecting procurement costs that are not captured because this model only varies with fleet size. As noted previously these additional factors include:

- The competitive situation for the particular procurement,
- The specific scope of the procurement (in particular, whether significant capital cost items such as radio system enhancements or a real-time passenger information system are included), and
- The effects of inflation of system prices over time (which may not match general price increases owing to inflation in the overall economy as a result of the ongoing price stability or even decreases in prices for computer hardware and software over time).

Nonetheless, this equation can help quantify the general magnitude for key elements of capital cost, with a central systems element that is relatively insensitive to the fleet size, and a component (e.g., for onboard systems) that is relatively proportional to fleet size.

In addition, there were fewer observations available for fleet sizes above 750 vehicles and the results seem more scattered, suggesting that other unknown variables were also significantly involved in determining these contract values and that a linear model based on fleet size alone would not seem very useful. For example, larger fleet systems can involve service areas of varying size, and a larger service area would require more expensive radio system enhancements (e.g., requiring more radio towers) if these are part of the system scope.

CHAPTER SEVEN

CONCLUSIONS

Bus automatic vehicle location (AVL) systems have been and continue to be an active area for transit agencies in North America and elsewhere, as well as for the systems integrators that serve this market. In the 1970s and 1980s, agencies in North America were first adopting an early generation of bus AVL technology using wayside "signpost" beacons as the location tracking method. By the late 1990s, agencies were generally adopting AVL systems using global positioning systems (GPS), which first became fully operational in 1995. GPS-based AVL systems addressed some of the key limitations of signpost-based AVL by eliminating the need for agencies to maintain the wayside signposts infrastructure.

Much of the AVL systems deployment focus in recent years has been on increasing the overall capabilities, sophistication, and degree of integration involved. Although the basic system architecture used over the past ten years has remained similar, AVL systems have progressed remarkably in their degree of functionality and reliability. There has been a trend toward increased integration between components and systems. The larger number of subsystems in modern AVL systems and the larger number of other types of technology deployed at transit agencies are driving this increasing degree of integration. Commercially available AVL systems are also increasingly incorporating rapid advances that have become available in overall communications, computing and networking technologies.

Today's bus AVL systems provide a great deal more functionality than the core location tracking capabilities. Optional features also commonly found in a modern bus AVL system include:

- Monitoring of additional "dead reckoning" devices to complement the GPS receiver in vehicle positioning. The most common is integration with the vehicle odometer, with another option being a heading sensor such as a compass or gyroscope.
- Managed voice communications, with dispatch initiating voice calls when needed and on receiving "Request to Talk" data request messages from operators.
- Text messaging data communications between operators and dispatch.
- Single point of onboard logon by means of the operator terminal (e.g., headsign and farebox).
- Onboard next stop announcements triggered automatically as the vehicle approaches the stop.
- Automatic headsign changes at the end of each trip.
- Onboard automatic passenger counter (APC) equipment to record the number of passengers boarding and alighting through each door at each stop.
- Monitoring vehicle mechanical status messages (i.e., from mechanical sensors or electronic control units for components such engine, transmission, and air conditioning), recording the data in the vehicle logic unit and/or transmitting to dispatch.
- Covert alarm to send an emergency message to dispatch, sometimes with a covert microphone for audio monitoring from dispatch.
- Wireless Local Area Network at vehicle storage areas to automate bulk data transfer between the central system and vehicle (e.g., to upload APC or maintenance data accumulated during a run, to download software updates for onboard devices).
- Use of schedule adherence and location data to develop real-time predictions for bus arrival times at stops and to provide these predicted arrival times to the public using methods including dynamic message signs at selected stops, telephone-based customer information systems, and websites.
- Improving the effectiveness of transit signal priority by making decisions on when to request and grant priority in part on the basis of real-time data on location, schedule adherence, and passenger loading.

AVL systems have also been increasingly adopted to support paratransit operations through integration of bus AVL onboard systems and mobile data communications with paratransit operations management software that supports trip booking, scheduling, and dispatch.

The survey questionnaire and case studies collected information from transit agencies on the characteristics of implemented bus AVL systems and on agency experiences with designing, procuring, implementing, and using these systems. Some interesting findings that emerged include:

- AVL is already widely used by U.S. transit agencies (e.g., the U.S.DOT reported that AVL technology had been deployed in 54% of all transit buses among respondents to their 2004 Intelligent Transportation Systems deployment survey).

- Although many survey respondents described various technical challenges experienced in deploying AVL systems, the experience among respondents with recent deployments seems to suggest that AVL technology is becoming more "mature," at least as it relates to core functionalities; survey respondents appear to have experienced fewer technical challenges in recent years than had been the case in the early years of deployment.
- Agencies reported deploying certain technologies significantly more often post-2003 compared with 2001 to 2003, which might be characterized as "recently established"; these technologies include paratransit scheduling and dispatch software integration, supervisor mobile access to AVL software, passenger information by means of interactive voice response, and cellular data service communications.
- Although agencies reported that they deployed most AVL technologies in most or all of the fleet, exceptions included transit signal priority, APCs, and integrated digital video recorders.
- Most responses reported using a single procurement with multiple deployment stages. This suggests complex yet integrated systems. The overall integrated nature makes it advantageous to use a single procurement, contracting with a single systems integrator that can serve as the sole point of accountability for system performance. The multiple rollout stages allow the agency to initially bring into operation a core functionality system that staff can adapt to using before additional subsystems are added. A common aspect of the staged rollout was an initial pilot deployment for a small portion of the overall fleet, on a test basis.
- Responding agencies received roughly 70% of capital costs for their AVL systems from federal and state sources, whereas local sources provide roughly 70% for operating costs.
- One interesting response notes that with comprehensive on-time performance data available (i.e., measured continuously at all timepoints or stops) it emerged that system on-time performance was far lower than previously measured with conventional methods. Using information about actual on-time performance, agencies can take steps to improve on-time performance by establishing more realistic schedules and addressing any underlying operational issues. However, it may be a good idea for an agency implementing a bus AVL system to prepare expectations for this potential scenario.
- The departments that most commonly had a significant level of involvement in developing, implementing, and using the system were Operations, Information Technology, Maintenance, and Planning. These departments were also the ones reported as having required the most significant adaptations to use the bus AVL system effectively. Although Operations uses the system in real time, Information Technology and Maintenance have important roles in keeping the system software and hardware available for use. Planning has a significant involvement by providing data needed by the system, such as scheduling data, and by analyzing system outputs (e.g., on-time performance and passenger counts). The most common uses indicated for archived system data were the scheduling of existing service and planning for service changes.
- Staff positions commonly reported as requiring retraining included operators, dispatchers, supervisors, maintenance technicians, Information Technology staff, customer service, and marketing.
- Some agencies reported having avoided the need to hire additional dispatchers or supervisors, presumably based on service level increases that would normally have been expected to require additional staff.
- The most commonly reported specific changes undertaken to adapt operations and organization for the effective use of the AVL system were that agencies altered procedures and provided training. Some of the specific challenges cited in such adaptations included underestimating the need for advance planning, ensuring support from throughout the organization, and securing changes to established business practices.
- Responses indicated that agencies may need to pursue further adaptation to fully utilize the potential of the system in the following areas: transit signal priority, next arrival predictions, and paratransit scheduling and dispatch.
- Areas where AVL systems were noted as having exceeded expectations included the ability of real-time location, schedule adherence, and passenger counts tracking to improve operations and generate useful passenger information.
- Areas where AVL systems were noted as having not met expectations included the challenges associated with managing the system implementation, the substantial ongoing effort needed for system maintenance and data management, staff resistance to accepting data as valid if it contradicts conventional understandings, and staff resistance to adopting needed changes in operational procedures.
- Key challenges reported for integration of the bus AVL system with existing technology included the interfaces with fixed-route scheduling software and paratransit scheduling and dispatch software, vehicle onboard integration with equipment including fareboxes and headsigns, and integration with the overall agency information technology environment.
- The biggest challenges with managing the development and implementation were reported as including strong project management and managing expectations throughout the agency.
- The biggest challenges with selecting the systems integrator were reported as the limited number of systems integrators with proven experience and the limited time and experience available among agency staff for a difficult decision involving unfamiliar technologies.

- To gain approval to implement the AVL system, agencies commonly needed to estimate capital costs, operating costs, and both the quantitative and qualitative benefits. Types of benefits commonly reported as important in gaining system approval were reported as "improve operating efficiency," "improve reporting or analysis capability," "improve safety and security," and "improve public information." The biggest challenges in gaining approval were reported as obtaining funding, justifying the cost, and working through agency approval procedures.
- The biggest challenges reported in defining the system functional requirements focused on establishing the internal consensus on the capabilities that were truly needed, proven, and cost-effective.
- Most agencies indicated that the agency business unit staff was involved in all stages of the deployment process, with some using dedicated agency project management staff. Consultants are an additional resource applied selectively by agencies, for areas where staff have less experience.
- Other reported "lessons learned" included the importance of securing participation from throughout the agency organization, carefully selecting the systems integrator, applying strong project management for the implementation, and understanding the substantial ongoing effort needed for system management once it is operational.
- In cases where the agency has not yet decided to implement an AVL system, commonly reported reasons included the need to understand the needs and technologies sufficiently, secure funds, or wait until they replace an associated technology such as the communications system.

It is recommended that this synthesis be updated at least every ten years. Because changes in technology and the acquisition of new experience in the effective use of bus AVL systems are happening at such a rapid pace, it may be productive to have the next update within five years. There have been considerable developments over the past decade in bus AVL systems technology and how they are integrated with other agency technology, as well as evolution in agency awareness of the impacts on and opportunities for the organization. A similar degree of evolution and adaptation can be expected over the upcoming 5 to 10 years, with the following emerging trends expected to be the driving factors over the next five years:

- Agency-wide data warehousing and reporting tools;
- Broadband mobile data communications, and new onboard applications that these will enable; and
- Mobile access and location-based services for traveler information services.

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GLOSSARY

ADA	Americans with Disabilities Act
APC	Automatic passenger counters
AVL	Automatic vehicle location
BRT	Bus rapid transit
CAD	Computer-aided dispatch
CDPD	Cellular Digital Packet Data
CMTA	Capital Metropolitan Transportation Authority
COTA	Central Ohio Transit Authority (Columbus)
DMS	Dynamic message signs
FTE	Full-time equivalent
GBTA	Greater Bridgeport Transit Authority
GIS	Geographic information systems
GPRS	General Packet Radio Service
GPS	Global Positioning System
IT	Information technology
ITS	Intelligent Transportation Systems
IVR	Interactive voice response
JPO	Joint program office
KCATA	Kansas City Area Transportation Authority
LAN	Local Area Network
LAVTA	Livermore Amador Valley Transit Authority
MAX	Metropolitan Area eXpress—BRT service in Kansas City, Missouri
MDT	Mobile data terminal
MMDI	Metropolitan Model Deployment Initiative
NTD	National Transit Database
PATH	Partners for Advanced Transit and Highways (University of California)
PRTC	Potomac and Rappahannock Transportation Commission
RFI	Request for Information
RFP	Request for Proposals
RPTA	Regional Public Transit Authority (Phoenix, Arizona, region)
RSA	Route schedule adherence
RTD	Regional Transportation District (Denver, Colorado)
RTT	Request to Talk
TCP	Transfer Connection Protection
TCP/IP	Transmission Control Protocol/Internet Protocol
TSP	Transit signal priority
TTA	Triangle Transit Authority
USC	University of Southern California
VAN	Vehicle Area Network
VLU	Vehicle Logic Unit
VMS	Vehicle Management System—Valley Metro (Phoenix region) AVL system
Wi-Fi	IEEE 802.11x-based wireless data communications technology
WiMAX	IEEE 802.16x-based wireless data communications technology
WLAN	Wireless Local Area Network

APPENDIX A

Survey Questionnaire

TCRP Synthesis SA-17
Questionnaire
AVL Systems for Bus Transit

1. Agency Information:

Date: ___________________________

Name and Title of Respondent: ____

Transit Agency Name: ____

Address:

____
____
____
____

Phone Number: _________________________________ Fax Number: __________________________________

Respondent's E-mail Address: ____

Purpose of this Survey: Bus Automatic Vehicle Location (AVL) systems are being increasingly implemented by transit agencies to enable improvements in operations and customer service, as well as in other areas such as planning, maintenance, and security. This survey focuses on:

- The characteristics of operational bus AVL systems;
- How systems were approved, procured, and implemented;
- How they are being used;
- Organizational effects; and
- Benefits/costs.

Once the survey results are reviewed, key agencies with extensive recent experience in implementing and using a bus AVL system will be selected for telephone interviews to gather more in-depth information. **All survey responses will be confidential.**

The final results of the survey will be synthesized into a report that will be published by the Transportation Research Board (TRB). **Thank you for taking the time to complete this survey!**

2. For each of the following modes, what fleet size (number of vehicles) does your agency either directly operate or subcontract?

	1–10	11–50	51–100	101–300	301–600	601–900	901–1200	1201+
Fixed-route bus								
Paratransit								
Heavy rail/subway								
Light rail/streetcar								
Bus rapid transit								
Commuter rail								
Ferry								
Other								

3. Please specify for any "Other" response in the previous question. ______________________________
____

4. Which of the following describes the status of bus AVL system development at your agency?
   - ☐ In revenue service and is being currently enhanced
   - ☐ In revenue service and is not being currently enhanced (skip to Question 6)
   - ☐ Being implemented (skip to Question 52)
   - ☐ Being procured (skip to Question 53)
   - ☐ Being planned (skip to Question 56)
   - ☐ No current interest (skip to Question 59)

5. Please indicate which of the following technologies, part of or integrated with a bus AVL system, your agency is implementing through the current enhancement effort:

Global Positioning System (GPS) Receivers	
Odometer Integration	
Heading Sensor	
Onboard Computer	
Operator Display/Keypad	
Interior Next Stop Announcements	
Exterior Announcements at Stops	
Automatic Passenger Counters	
Covert Alarm Monitoring	
Covert Microphone Monitoring	
Transit Signal Priority	
Drivetrain Monitoring	
Headsign Integration	
Farebox Integration	
Digital Video Recorder Integration	
Mobile Radio Integration	
Mobile Radio System Enhancements	
Cellular Data Service Integration	
Wireless Local Area Network Integration	
AVL Software for Fixed-Route Operations	
Fixed-Route Scheduling Software Integration	
Paratransit Scheduling/Dispatch Software Integration	
Data Warehouse Integration	
Display/Keypad and Location Monitoring for Non-Revenue Vehicles	
Supervisor Mobile Access to AVL Software	
Next Arrival Predictions via Signs at Stops	
Next Arrival Predictions via Automated Telephone System	
Next Arrival Predictions via Website	
Next Arrival Predictions via Website, for Access with Mobile Personal Devices	
Next Arrival Predictions via E-mail Subscription	
Other (please specify): ______________________ ______________________	

6. Please indicate time periods when your agency implemented any of the following technologies, part of or integrated with a bus AVL system, and whether maintenance and support is currently provided under warranty:

	1994 or Earlier	1995–1997	1998–2000	2001–2003	2004 or later	Currently under Warranty?
Transponder or Transponder Receiver ("Signpost" Technology)						
Global Positioning System (GPS) Receivers						

Odometer Integration						
Heading Sensor						
Onboard Computer						
Operator Display/Keypad						
Interior Next Stop Announcements						
Exterior Announcements at Stops						
Automatic Passenger Counters						
Covert Alarm Monitoring						
Covert Microphone Monitoring						
Transit Signal Priority						
Drivetrain Monitoring						
Headsign Integration						
Farebox Integration						
Integrated Digital Video Recorder						
Mobile Radio Voice Communications Integration						
Mobile Radio Data Communications						
Mobile Radio System Enhancements						
Cellular Data Service Communications						
Wireless Local Area Network Communications						
AVL Software for Fixed-Route Operations						
Fixed-Route Scheduling Software Integration						
Paratransit Scheduling/Dispatch Software Integration						
Dispatch Center Workstation Furniture						
Data Management System Integration						
Central System Hardware/Software Upgrades						
Display/Keypad and Location Monitoring for Non-Revenue Vehicles						
Supervisor Mobile Access to AVL Software						
Next Arrival Predictions via Signs at Stops						
Next Arrival Predictions or Paratransit Trip Information via Automated Telephone System						
Next Arrival Predictions or Paratransit Trip Information via Website						
Next Arrival Predictions or Paratransit Trip Information via Website, for Access with Mobile Personal Devices						

Next Arrival Predictions or Paratransit Trip Information via E-Mail Subscription						
Other						

7. Please specify for any "Other" response in the previous question. ____________________

8. Please indicate for any of the following technologies, part of or integrated with a bus AVL system, the portion of the fixed-route bus fleet your agency has equipped:

	1%–20%	21%–40%	41%–60%	61%–80%	81%–100%
Transponder or Transponder Receiver ("Signpost" Technology)					
Global Positioning System (GPS) Receivers					
Odometer Integration					
Heading Sensor					
Onboard Computer					
Operator Display/Keypad					
Interior Next Stop Announcements					
Exterior Announcements at Stops					
Automatic Passenger Counters					
Covert Alarm Monitoring					
Covert Microphone Monitoring					
Transit Signal Priority					
Drivetrain Monitoring					
Headsign Integration					
Farebox Integration					
Integrated Digital Video Recorder					
Mobile Radio Voice Communications Integration					
Mobile Radio Data Communications					
Cellular Data Service Communications					
Wireless Local Area Network Communications					
Other					

9. Please specify for any "Other" response in the previous question. ____________________

10. Please indicate for any of the following technologies, part of or integrated with a bus AVL system, the portion of the paratransit bus fleet your agency has equipped:

	1%–20%	21%–40%	41%–60%	61%–80%	81%–100%
Global Positioning System (GPS) Receivers					
Odometer Integration					
Heading Sensor					
Onboard Computer					
Operator Display/Keypad					
Covert Alarm Monitoring					
Covert Microphone Monitoring					
Drivetrain Monitoring					

Farebox Integration					
Integrated Digital Video Recorder					
Mobile Radio Voice Communications Integration					
Mobile Radio Data Communications					
Cellular Data Service Communications					
Wireless Local Area Network Communications					
Other					

11. Please specify for any "Other" response in the previous question. ______________________________

12. Please indicate the approximate service area (in square miles) supported by your bus AVL system:

Fixed Route	

13. Please indicate the approximate service area (in square miles) supported by your bus AVL system:

Paratransit	

14. Please indicate the equipment suppliers and integrators for the technologies, part of or integrated with a bus AVL system, that your agency has implemented: ______________________________

15. At what time interval (in seconds) are AVL location reports received from any particular vehicle in your bus AVL system (e.g., many systems poll the fleet such that the location is updated for each vehicle every 60–120 seconds)?

____

16. Which of the following best describes how your agency deployed the bus AVL system?
    - ☐ With a single procurement and a single deployment stage
    - ☐ With a single procurement and multiple rollout stages
    - ☐ With multiple procurements

17. Please indicate the cumulative capital cost for your bus AVL system, on a per equipped vehicle basis (please attempt to include the full range of capital costs associated with the system, including the costs for vehicles and central systems, but exclude any capital costs for mobile radio system enhancements).
    - ☐ U$10,000 or less
    - ☐ U$10,001–U$20,000
    - ☐ U$20,001–U$30,000
    - ☐ U$30,001–U$40,000
    - ☐ U$40,001–U$50,000
    - ☐ U$50,001–U$60,000
    - ☐ U$60,001–U$70,000
    - ☐ U$70,001–U$80,000
    - ☐ U$80,001–U$90,000
    - ☐ U$90,001–U$100,000
    - ☐ More than U$100,000

18. Please indicate any capital cost for mobile radio system enhancements needed to support your bus AVL system, on a per equipped vehicle basis.
    - ☐ U$1,000 or less
    - ☐ U$1,001–U$2,000
    - ☐ U$2,001–U$3,000
    - ☐ U$3,001–U$4,000
    - ☐ U$4,001–U$5,000
    - ☐ U$5,001–U$6,000
    - ☐ U$6,001–U$7,000
    - ☐ U$7,001–U$8,000

☐ U$8,001–U$9,000
☐ U$9,001–U$10,000
☐ More than U$10,000

19. Please indicate the approximate breakdown for the sources of the capital costs for your bus AVL system, on a percentage basis:

Federal ITS grant	
Other federal funding	
State funding	
Local funding	
Agency revenues	

20. Please indicate the approximate breakdown for the sources of the operating costs for your bus AVL system, on a percentage basis:

Federal ITS grant	
Other federal funding	
State funding	
Local funding	
Agency revenues	

21. Please indicate the current operating cost that you feel is directly attributable to your bus AVL system, on a per equipped vehicle basis (please attempt to include the full range of operating costs, including maintenance, incremental staffing, and training/retraining).
☐ U$1,000 or less
☐ U$1,001–U$2,000
☐ U$2,001–U$3,000
☐ U$3,001–U$4,000
☐ U$4,001–U$5,000
☐ U$5,001–U$6,000
☐ U$6,001–U$7,000
☐ U$7,001–U$8,000
☐ U$8,001–U$9,000
☐ U$9,001–U$10,000
☐ More than U$10,000

22. Please indicate any additional comments or detail about the composition and/or staged deployment of your bus AVL system.
____
____
____
____
____

23. Can we contact you for press releases issued about your bus AVL system, for use in this Synthesis project?
☐ Yes ☐ No

24. Can we contact you for evaluation results about your bus AVL system performance and how you are using the system, for use in this Synthesis project?
☐ Yes ☐ No

25. Can we contact you for the results for any surveys and/or focus groups conducted to gather customer feedback on your bus AVL system and how you are using it, for use in this Synthesis project?
☐ Yes ☐ No

26. What bus AVL system technologies, and ways of using these technologies, have been most effective with your agency (and why)? ________________________________
____
____
____
____

27. Please indicate the degree to which each of the following agency business units was involved in the effort to develop and implement your bus AVL system:

	Not Involved 1	2	3	4	Significant and Ongoing Involvement 5
Operations					
Maintenance					
Customer Service					
Security					
Information Technology					
Planning					
Revenue					
Marketing					
Training and Human Resources					
Other					

28. Please specify for any "Other" response in the previous question. ____
____

29. Please indicate the degree to which each of the following agency business units are involved in the ongoing use and operation of your bus AVL system:

	Not Involved 1	2	3	4	Significant and Ongoing Involvement 5
Operations					
Maintenance					
Customer Service					
Security					
Information Technology					
Planning					
Revenue					
Marketing					
Training and Human Resources					
Other					

30. Please specify for any "Other" response in the previous question. ____
____

31. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Operations business unit, in the revenue service phase for your bus AVL system.

Job Title	Number FTEs Hired	Number FTEs Retrained	Number FTEs Avoided

32. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Maintenance business unit, in the revenue service phase for your bus AVL system.

Job Title	Number FTEs Hired	Number FTEs Retrained	Number FTEs Avoided

33. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Customer Service business unit, in the revenue service phase for your bus AVL system.

Job Title	Number FTEs Hired	Number FTEs Retrained	Number FTEs Avoided

34. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Security business unit, in the revenue service phase for your bus AVL system.

Job Title	Number FTEs Hired	Number FTEs Retrained	Number FTEs Avoided

35. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Information Technology business unit, in the revenue service phase for your bus AVL system.

Job Title	Number FTEs Hired	Number FTEs Retrained	Number FTEs Avoided

36. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Planning business unit, in the revenue service phase for your bus AVL system.

Job Title	Number FTEs Hired	Number FTEs Retrained	Number FTEs Avoided

37. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Revenue business unit, in the revenue service phase for your bus AVL system.

Job Title	Number FTEs Hired	Number FTEs Retrained	Number FTEs Avoided

38. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Marketing business unit, in the revenue service phase for your bus AVL system.

Job Title	Number FTEs Hired	Number FTEs Retrained	Number FTEs Avoided

39. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in the Training and Human Resources business unit, in the revenue service phase for your bus AVL system.

Job Title	Number FTEs Hired	Number FTEs Retrained	Number FTEs Avoided

40. Please indicate the number of staff (full-time equivalents) hired, retrained, or avoided (i.e., if you feel that the need to hire additional staff has been avoided through additional productivity from having the system) in other business units (beyond the business units discussed in the previous sequence of questions), in the revenue service phase for your bus AVL system.

Job Title	Number FTEs Hired	Number FTEs Retrained	Number FTEs Avoided

41. Please indicate the degree to which each of the following agency business units needed to adapt their organization and operations to use your bus AVL system effectively:

	Not Affected 1	2	3	4	Significant Changes Needed 5
Operations					
Maintenance					
Customer Service					
Security					
Information Technology					
Planning					
Revenue					
Marketing					
Training and Human Resources					
Other					

42. Please specify for any "Other" response in the previous question. ______________________________

____

43. Please indicate any of the following specific changes that were undertaken for each agency business unit, in order to adapt their organization and operations to use your bus AVL system effectively:

	Increase Staff	Provide Training	Alter Procedures	Alter Organizational Structure	Other
Operations					
Maintenance					
Customer Service					
Security					
Information Technology					
Planning					
Revenue					
Marketing					
Training and Human Resources					
Other					

44. Please specify for any "Other" response in the previous question. ______________________________

____

45. Please indicate any of the following aspects of your bus AVL system where you feel the potential has not been fully utilized to date, as a result of adaptations yet needed to the organization and operations to use it effectively.

AVL Software for Fixed-Route Operations	
Next Stop Announcements	
Automatic Passenger Counters	
Transit Signal Priority	
Next Arrival Predictions	
Scheduling and Dispatch Software for Paratransit Operations	
Other	

46. What was the one biggest challenge associated with adapting agency organization and operations to implementing and operating your bus AVL system? ______________________________

____

____

____

____

47. Please indicate any of the following uses your agency has adopted for archived data from your AVL system.
    - ☐ Scheduling
    - ☐ Planning
    - ☐ Maintenance
    - ☐ Marketing
    - ☐ Third Part Research (e.g., universities)
    - ☐ Other (please specify): ______________________________

48. What was the biggest way in which your bus AVL system has met or exceeded the expectations the agency had when the decision was made to deploy? ______________________________

49. What was the biggest way in which your bus AVL system has not met expectations the agency had when the decision was made to deploy? ______________________________

50. What was the one biggest challenge associated with effectively integrating your bus AVL system with other agency technology? ______________________________

51. What was the one biggest challenge associated with managing the development and implementation of your bus AVL system? ______________________________

52. What was the one biggest challenge associated with selecting the systems integrator for your bus AVL system? ______________________________

53. Please indicate which of the following needed to be estimated as part of gaining approval to implement your bus AVL system:
    - ☐ Capital costs
    - ☐ Operating costs
    - ☐ Measurable benefits
    - ☐ Subjective benefits

54. Please indicate any of the following factors that were important in gaining approval to implement your bus AVL system:
    - ☐ Improve operating efficiency
    - ☐ Improve public information
    - ☐ Improve safety and security
    - ☐ Modernize public image of transit agency
    - ☐ Improved reporting or analysis capability
    - ☐ Benefits expected to exceed costs
    - ☐ Other (please specify): ______________________________

55. What was the one biggest challenge associated with gaining approval to implement your bus AVL system? ______________________________

56. What was the one biggest challenge associated with defining the functional capabilities for your bus AVL system?

57. Please identify which agency resources were involved in each of the following stages that have been completed for bus AVL system development at your agency:

	Agency Business Units Staff	Agency Dedicated Project Management Staff	Consultants
Needs Assessment			
Technology Assessment			
Projects Definition			
Implementation Plan			
Project Approval			
Functional Specifications			
Solicitation			
Selection of Systems Integrator			
Implementation Management			
Evaluation			

58. Please describe any additional "lessons learned" that would benefit transit agencies that are considering bus AVL systems.

59. Are there other agencies you would suggest we should speak to regarding "best practices" in bus AVL systems? If so, please provide contact information.

60. If your agency has not yet decided to implement a bus AVL system, what is the biggest reason?

Please Return the Completed Questionnaire by January 29, 2007 to:

Mr. Doug J. Parker
Senior Transportation Planner
TranSystems Corporation
46 Barwick Drive, Suite 100
Barrie, Ontario, Canada
L4N 6Z5
Telephone: 416-628-4331
Fax: 781-396-7757
E-mail Address: djparker@transystems.com

We encourage you to return your completed survey to Mr. Parker via e-mail at djparker@transystems.com. If you have any questions on the survey or the project, please do not hesitate to call Mr. Parker. Thank you very much for your participation in this important project.

APPENDIX B

Overview of Current Bus AVL Systems

GENERAL ROLE WITHIN AGENCIES

The core role of a bus automatic vehicle location (AVL) system, whether for fixed-route or paratransit (demand responsive) operations, is to support operators, supervisors, and dispatchers during their real-time fleet operations management. As these systems typically provide to dispatch real-time operations support data well beyond simply fleet location, they are often referred as AVL systems. In addition, these systems often collect service planning support data, provide real-time customer information, and support onboard integration with other systems.

Figure B1 shows a high level overview for a generalized bus AVL system, as defined for the purposes of this synthesis. This system includes a mobile communications system supporting data exchange between fleet vehicles and central computer system, as well as the dissemination of real-time customer information from the central computer system via dynamic message sign (DMS) at selected stops.

FIXED ROUTE

For fixed-route operations, a typical AVL system supports real-time fleet operations management by providing operators with real-time schedule adherence feedback and by providing dispatchers with real-time data on the locations and status of all fleet vehicles (typically including both revenue and non-revenue vehicles). Voice and data communication management between dispatchers and fleet vehicles is usually also incorporated into the AVL system. The onboard equipment is sometimes integrated with automatic passenger counter (APC) and automated next stop announcements. AVL and APC data are commonly archived for management analysis. The system can provide real-time customer information based on the fleet location and schedule adherence data using methods such as DMS at selected stops. The system can also provide real-time customer information through additional methods defined as outside the boundaries of a bus AVL system as defined for the purposes of this synthesis, including interactive voice response (IVR) telephone information systems and web-based applications.

PARATRANSIT

For paratransit operations, the AVL system is commonly integrated with specialized paratransit software for scheduling and dispatch operations management, which supports trip booking, run scheduling, and same-day changes. The onboard operator interface focuses on displaying the manifest of upcoming pickups and dropoffs, and allowing the operator to send in real-time data as manifest trip events are completed. The system can provide real-time customer information for trip booking, confirmation, cancellation, and for vehicle approach, using methods such as IVR telephone information systems and web-based applications.

FUNCTIONAL CAPABILITIES

This section provides additional detail on typical functional capabilities for an AVL system that supports fixed-route and paratransit operations:

- Onboard—Fixed-Route Vehicles
  - Log in to a run;
  - Log in simultaneously to the AVL system and other onboard devices requiring operator login (e.g., farebox and headsign);
  - Continuously determine location in real time;
  - Track schedule and route adherence and transmit these data to the operator;
  - Send location, schedule adherence, and route adherence status and other status data to dispatch on a frequent periodic basis (note that the specific polling interval, such as to get a report from the entire fleet every 90 s, is usually determined by the capacity of the mobile data communications system);
  - Send canned text messages from operator to dispatch;
  - Send operator request for a voice call from dispatch;
  - Send operator input on the routes boarding passengers will transfer to, and receive feedback on the transfer connection protection (TCP) status for these requests;
  - Allow the operator to covertly send an emergency alarm data message;
  - Provide route and trip segmentation and fareset data to the farebox;
  - Automatically change the headsign destination at the end of trips;
  - Provide automated passenger interior announcements of the stop name as the vehicle approaches;
  - Provide automated passenger exterior announcements of the route and destination once the door opens at a stop;
  - Collect APC data, recording the number of passengers boarding and alighting through each door at each stop (based on these data, the system sometimes also tracks the current onboard load);
  - Use schedule adherence status to request TSP only when the vehicle is running late; and

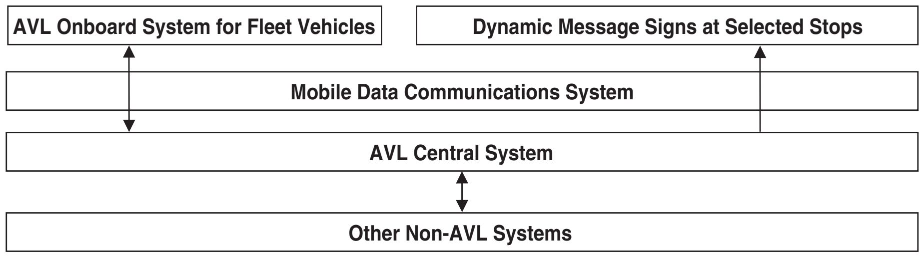

FIGURE B1 Generalized AVL system overview.

  - Monitor the mechanical status of key components (i.e., from mechanical sensors or electronic control units for components such as engine, transmission, and air conditioning), recording the data and/or transmitting to dispatch.
- Onboard—Paratransit Vehicles
  - Log in to a run;
  - Determine location in real time;
  - Receive manifest of pickups and dropoffs, and manifest changes;
  - Send real-time updates as manifest trip events are completed;
  - Send canned text messages from operator to dispatch; and
  - Send operator request for a voice call from dispatch.
- Onboard—Non-Revenue Vehicles
  - Log in;
  - Determine location in real time;
  - Send canned text messages from operator to dispatch; and
  - Send operator request for a voice call from dispatch.
- Central Systems
  - Show real-time current fleet locations, schedule adherence, route adherence, and other fleet status events to dispatchers, using a map and tabular displays;
  - Provide the ability to manage the work assignments of multiple dispatchers and to support a strategy of particular dispatchers managing given vehicles, routes, or zones;
  - Send canned or free-form text messages to one or more operators;
  - Initiate voice calls to one or more operators, whenever needed, and on receiving a voice call Request to Talk (RTT) from an operator;
  - Receive TCP requests from inbound fixed-route vehicles, provide feedback on the status of these requests, and issue hold instructions to outbound vehicles when needed;
  - Listen to audio from a vehicle that sent in a covert emergency alarm;
  - Log the disposition of and actions taken in response to fleet status events;
  - Create and log incident reports;
  - Support mobile workstations in non-revenue vehicles that can provide a limited functional version of dispatcher software, supporting fleet monitoring, text messaging, logging, incident reports, and playback;
  - Provide information for customer service agents to help address customer questions and concerns, including the ability to "play back" the movements and status of a selected vehicle over a given period;
  - Provide information to maintenance managers to assist in directing road call vehicles to the locations of buses requiring service;
  - Build a historical database that includes vehicle location, vehicle status, logs, incident reports, and APC data;
  - Periodically generate a variety of canned reports and provide a method to generate ad hoc reports (the effective definition of useful canned reports requires input from agency business units during the implementation, and the ongoing effective generation of ad hoc reports requires that the agency develop in-house expertise with the system databases and the ad hoc reporting tools);
  - Interface with paratransit operations software for scheduling and dispatch management to exchange manifest and trip completion data between this software and paratransit vehicles; and
  - Use schedule adherence and location data to develop real-time predictions for bus arrival times at stops and to provide these predicted arrival times to customers.
- Selected stops
  - Use DMS to provide next arrival predictions and other real-time customer information (e.g., delays).

SYSTEM COMPONENTS

In general a current generation bus AVL system, based on the AVL system boundaries as defined for this synthesis, includes the following system components:

- Onboard—Fixed-Route Revenue Vehicles (see Figure B2)
  - Global positioning system (GPS) receiver and antenna;
  - Additional "dead reckoning" devices to complement the GPS receiver for vehicle positioning; the most common is integration with the vehicle odometer, with another option being a heading sensor such as a compass or gyroscope;
  - Vehicle logic unit (VLU) computer;
  - Mobile data terminal (MDT) operator interface terminal;

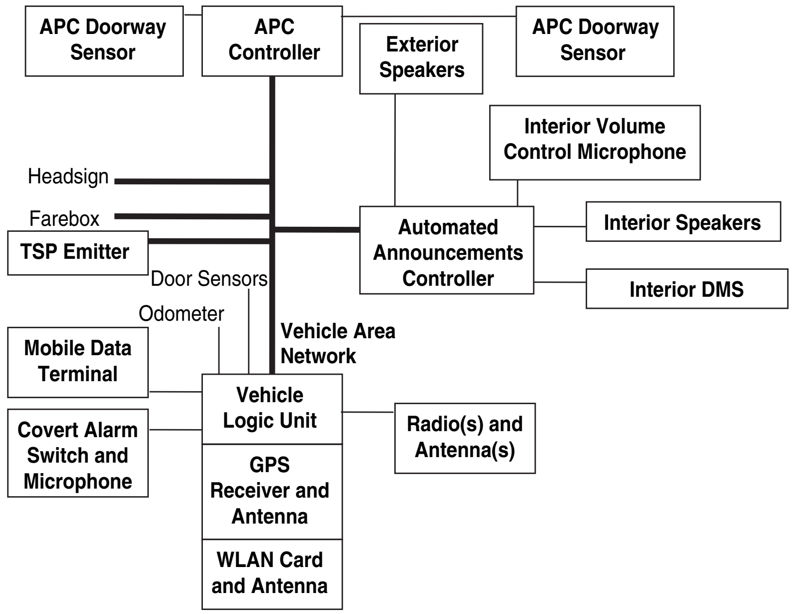

FIGURE B2 Fixed-route vehicle system components.

- – One or more radios and antennas to provide wide-area voice and data communications;
- – Wireless local area network (WLAN) (card and antenna to provide bulk data communications at the garage (the use of standard 802.11x WLAN technology for this purpose has in recent deployments largely superseded the earlier use of physical data transfer using memory cards, although such technologies are still in use in many in-service systems);
- – APC subsystem, including doorway sensors and controller;
- – Automated onboard announcements subsystem, including DMS, speakers, and controller;
- – TSP emitter; and
- – Data network to support communications between onboard devices.

- Onboard—Non-Revenue Vehicles and Paratransit Revenue Vehicles (see Figure B3)
  - – GPS receivers;
  - – VLU computer;
  - – MDT operator interface terminal;

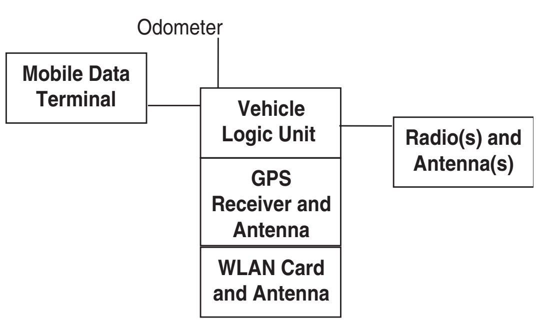

FIGURE B3 Non-revenue vehicle and paratransit revenue vehicle system components.

  - – One or more radios to provide wide-area voice and data communications; and
  - – WLAN card to provide bulk data communications at the garage.
- Central Systems:
  - – Servers, workstations, and network;
  - – Mobile workstations for selected non-revenue vehicles;
  - – Mobile communications gateways;
  - – WLAN access points network at garages;
  - – Dispatcher software with map and tabular displays showing real-time fleet locations, schedule adherence, and other fleet status information;
  - – APC management software, referring to the software used to manage the processing of APC data received from fleet vehicles;
  - – Software to record and set the text for onboard announcements (some systems use text-to-speech software instead of recording for the audio announcements);
  - – Central database; and
  - – Management software for real-time customer information.
- Selected Stops
  - – DMS to present next arrival predictions and other real-time customer information (e.g., delays and AMBER Alert messages).

MOBILE COMMUNICATIONS

Mobile data communications provide the means for the data communications between components on the vehicle and for vehicles (and also often the DMS at stops) to exchange data with the central system. As such, mobile data communications in this sense covers all system communications beyond the wired Local Area Network (LAN) on agency premises and will be discussed in the following categories:

- Onboard
- Wide area
- Garage bulk data transfer.

Onboard Communications

Onboard data communications between components typically use wired connections. Some vehicle signals are monitored for discrete state changes (e.g., door sensor relays) or analog outputs (e.g., odometer pulses). Some onboard AVL system components are directly connected to the VLU as a peripheral device (e.g., MDT and radio), using a serial communications link based on a common computer industry standard such as IEEE RS-232 or in some cases a proprietary interface. For such interfaces, even when IEEE RS-232 or a similar standard is used this typically only defines the physical interface; the software interface is typically proprietary.

Onboard components in the AVL system from multiple vendors are commonly interconnected using a standards-based serial communications data network to help support interoperability, with many implemented onboard networks for buses conforming to SAE J1708/J1587 or SAE J1939 standard. The most commonly deployed vehicle area network for bus AVL onboard equipment in recent years has been the SAE J1708/J1587 standard. This standard supports interoperability to the extent that SAE J1708 defines the physical interface and SAE J1587 defines a standard set of data messages compatible with transmission over an SAE J1708 network. However, the SAE J1708/J1587 onboard communications software with any particular device typically only supports a subset of the overall SAE J1587 message set and the use of certain message types that allow for customized content. As a result, it is essential that all onboard devices using SAE J1708/J1587 communications be supplied with sufficient documentation of the specific messages used to allow another vendor to communicate with it over the vehicle area network.

An emerging trend in onboard communications is the potential for using an alternative wired network or a short-range wireless standard.

- The primary alternative for a wired onboard network is an IEEE 802.3 Ethernet network. With an Ethernet onboard LAN, devices can use networking technologies common in the overall information technology industry such as Transmission Control Protocol/Internet Protocol (TCP/IP) and operate with a higher bandwidth. However, this requires use of the same type of cabling typical for an office LAN, which is thicker than J1708 cabling and poses some limitations for onboard use related to being pulled through tight spaces and the extra weight.
- The options for wireless onboard communications include using a standard IEEE 802.11x WLAN (i.e., Wi-Fi) or one of the other "Personal Area Networks" short-range communications technologies [e.g., Bluetooth and Zigbee (*B1*)].

Wide-Area Communications

Radio Voice

Most urban bus transit agencies have had a voice radio wide-area communications system in place for decades, having been granted control of one or more radio channels by the Federal Communications Commission (or similar governmental regulatory agencies outside of the United States). Each radio channel consists of a frequency pair and supports bi-directional communications. These channels commonly use frequencies in the 450, 700, 800, or 900 MHz bands. Conventionally, bus transit voice radio systems have allowed any radio user (e.g., dispatch, supervisors, and operators) to initiate a voice transmission whenever the channel is available, and to hear any voice transmission on the channel (commonly referred to as "open voice").

This can be provided by dedicating each radio channel to a certain set of users. Alternatively, a set of radio channels can be "trunked," wherein a radio control system temporarily assigns one of the channels when a radio needs to initiate a call (voice transmissions can be heard by other radios configured as part of the same "talkgroup"). Open voice operation is challenging for dispatchers, as it is difficult to effectively monitor simultaneous communications from operators and supervisors.

Coverage is accomplished with antennas mounted on an array of towers distributed throughout the transit agency service area; that is, each tower covers a certain radius. The towers, antennas, and associated tower site infrastructure are in some cases owned by the transit agencies but are often leased from tower site owners. The voice radio audio is carried to the towers by:

- Transmission of a signal from dispatch that is received and "repeated" from the tower (and the reverse for inbound transmissions from vehicles), or
- Use of communications links (typically leased) between dispatch and the towers.

Cellular Voice

Cellular phones are available as an alternative to radio for wide-area voice communications. It is challenging for dispatchers to manage cellular phone use for fleet voice communications (i.e., receiving multiple calls at the same time). Common reasons for using cellular phones, instead of or to complement a voice radio system, include:

- Operating in a relatively extensive or rural service area where setting up voice radio communications infrastructure would be relatively expensive,
- Expanding into a new service area, and
- Initiating a new or small transit service.

Radio Data

A bus AVL system requires mobile data communications between the central system and operating fleet vehicles, and often also for communications between the central system and the DMS at selected stops. This supports the various real-time data communications that a bus AVL system requires.

Another common function is to use mobile data communications to support dispatcher-managed initiation of voice calls. A dispatcher can initiate a voice call to one or more fleet vehicles whenever needed, but a fleet vehicle can only send an "RTT" data message to dispatch (there is also often a "Priority Request to Talk (PRTT)" message that vehicles can use in prescribed situations). Dispatchers initiate two-way voice calls in response to the received RTT and PRTT messages. When individual dispatchers need to listen to all incoming voice transmissions from a larger number of vehicles, dispatcher-managed voice calls tend to be considered more needed.

Some bus AVL systems also use data communications to manage use of the voice radio system for the covert alarm function. When the vehicle operator presses this alarm switch, it sends a data message to dispatch. In addition to signaling to dispatch the emergency vehicle status, when a vehicle is in emergency mode dispatch it often has the additional capability to receive one-way inbound audio over a voice frequency from a covert microphone in the operator area (i.e., to help dispatch assess the emergency without using a two-way voice call that could potentially exacerbate the onboard emergency).

Each fleet vehicle can be equipped with two radios: one for voice and one for data. However, agencies often avoid the additional capital expense by using the onboard system to control the shared use of a single radio between voice and data. Because data are frequently being exchanged between the vehicles and central dispatch (e.g., for periodic location and status reports), the radio typically uses data mode as the default state. When dispatch initiates a voice call with a particular vehicle, this system sends a data message to the vehicle that commands it to switch the radio to voice mode for a defined interval. While the radio is temporarily in voice mode, data communications with the vehicle is not available (except for the option of sending brief bursts of data that would interfere with audio transmissions). While monitoring the covert microphone in emergency mode, the system must periodically interrupt the audio transmission so that the radio does not overheat from transmitting continuously; this brief interruption is commonly used to send a location and status update.

One or more dedicated radio channels are normally set up for data, one or more of which the agency could opt to convert from current voice communications use. Channels cannot be readily shared between voice and data use because with a shared channel all vehicles in the fleet would need to stop transmitting data to allow a voice call on the channel to transmit it without interference. For the same reason, data channels must be kept separate from the pool of channels used for voice communications in a trunked voice system. Trunked radio systems inherently include a limited data transmission capability (i.e., a radio sent data to the trunking control system to request assignment of a voice channel); however, this data capacity is usually not considered adequate to support a bus AVL system. The number of radio data channels needed for an AVL system depends on factors including the fleet size, polling rate (e.g., all vehicles in the fleet are polled every 90 s), and the efficiency of the polling algorithm used in a particular AVL system.

Cellular Data

As with voice communications, cellular data service is available in most areas as an alternative to radio system data communications. This might be done, for example, if the additional radio channels needed to support data communications were not available from the Federal Communications Commission or if data coverage was needed in an area beyond the coverage provided by available towers. Cellular data plans providing 5 MB per vehicle per month have generally been found suitable for supporting a bus AVL system, although the specific data capacity required will depend on the details of how the data system is used (e.g., location and status reports frequency and extent of text messaging use).

Cellular data provide a higher data transmission rate than is usually available with data transmission over radio channels [common radio system data rate is 9.6 kilobits per second (kbps)]. A typical cellular data system that is currently widely deployed in the United States is Evolution—Data Optimized (EVDO) Rev 0, with theoretical maximum data rate at 2.4 megabits per second (Mbps), with 300–600 kbps more common in practical use (*B2*). Agency concerns with cellular data include the monthly account fees and the potential for cellular systems to sometimes become overloaded during emergencies (i.e., owing to the infrastructure being shared with the general public). In comparing monthly costs with the radio alternative, agencies should take into consideration the operating and maintenance costs involved in having a radio communications system.

Some AVL systems now equip one or more supervisors with a limited functionality version of the dispatcher AVL software, operating on a laptop computer in their vehicle. This provides supervisors with enhanced abilities (e.g., more readily able to locate fleet vehicles and monitor schedule/route adherence, and complete incident reports). Such a mobile AVL workstation requires the additional data transmission rate supported by cellular data for effective operation (and to avoid overwhelming the data capacity available with radio data channels). In some cases, agencies have adopted the use of cellular data for this role, while using radio system data transmission otherwise.

High Data Rate Alternatives

In recent years, additional high data rate mobile communications alternatives have been emerging. These alternatives include "mesh" networks incorporating various technologies.

- One approach uses 900 MHz radio technology, which can be thought of as a higher data rate radio system (1–3 Mbps) that needs a higher density of access points (analogous to radio system towers) because of the reduced coverage from each access point.
- A similar approach would use IEEE 802.11x WLAN "hotspots" instead. Relative to 900 MHz access points, IEEE 802.11x access points offer higher data rates and reduced coverage per access point [e.g., an IEEE 802.11g access point offers a theoretical maximum data rate of 54 Mbps up to about 90 ft (*B3*), with the data rate stepping down at greater range]. A limitation with using this approach for mobile data communications is that the IEEE 802.11x WLAN technology was not explicitly designed for mobile access, meaning that it is difficult to maintain the connection once the vehicle is moving at any significant speed.
- The "mesh" aspect frequently incorporated into such systems refers to the fact that every access point need not have a direct communications link back to dispatch (commonly called the "network backhaul"), thereby reducing the cost considering the large number of dispersed access points involved. Instead, some access points act as repeaters to pass the communications wirelessly to an access point that has a network backhaul. In a mesh network, users can configure the system with the onboard data communications system equipment serving as additional repeaters.
- In some networks, some of the access points that concentrate data traffic from other access points (i.e., using mesh technology) may not have a wired network backhaul. Instead, they may use a high-capacity data link to send the data to where it can connect with the wired network backhaul. IEEE 802.16 (WiMax) is a communications technology often used in this role, because it can transmit a high data rate and over a longer distance—40 Mbps out to about 10 km (*B4*).
- Conventional IEEE 802.16 WiMax has the limitation (similar to IEEE 802.11x WLANs) that it was not explicitly designed for use with moving vehicles. An emerging development is IEEE 802.16e Mobile WiMax, which supports connection with moving vehicles, up to about 120 km per hour (*B5*). This suggests that in time Mobile WiMax could be used for direct communication with the vehicles (i.e., eliminating the role of 900 MHz technology or IEEE 802.11x WLANs).

A transit agency could implement this type of high data rate wide-area mobile communications network on its own or in collaboration with other public sector partners in its region (i.e., analogous to the conventional approach with radio systems). It could also lease an account to use a commercial system, if such systems become established in its region (i.e., analogous to leased cellular data approaches available today).

Any agency intentions to create an IEEE 802.11x WLAN hotspot onboard vehicles for public Internet access, although not addressed in this synthesis, would certainly affect agency decisions related to the most effective wide-area mobile data system.

Garage Bulk Data Transfer

Many bus AVL systems support bulk data transfer at vehicle storage areas, such as their bus garages. This typically involves setting up an IEEE 802.11x WLAN, because this technology can operate effectively with vehicles that are stopped or moving at low speeds.

The role of this bulk data transfer zone is to provide a regular opportunity (e.g., daily) to exchange with each vehicle the following data that do not require real-time transmission, to relieve the volume of data transmission that needs to be accommodated with the wide-area mobile data communications system:

- Bulk data to be downloaded to vehicles, including firmware updates and configuration data updates (e.g., run schedules and automated announcement audio files).
- Bulk data to be uploaded from vehicles, including APC data (although some bus AVL systems opt to transmit APC in real time if the data communications system can support this) and maintenance monitoring data (i.e., for maintenance data that there is no need to collect before the bus returns to the garage).

Important considerations in implementing such garage bulk data transfer systems include:

- The challenge in deciding which type of IEEE 802.11x WLAN technology to use.
  - IEEE 802.11g offers the increased maximum theoretical data rate of 54 Mbps relative to the 11 Mbps maximum rate available from IEEE 802.11b technology. However, this increased data rate is only available within a more limited range from each access point (i.e., an IEEE 802.11g WLAN network would require more access points than an IEEE 802.11b network to provide the increased data rate throughout the coverage area).

  - Many bus AVL systems integrators offer proven off-the-shelf support for the integration of IEEE 802.11b access cards with their VLUs, but in many cases integrators have not yet upgraded their standard solution to support IEEE 802.11g.
  - Meanwhile, IEEE 802.11n, although still at the pre-standard stage, appears to be emerging as the next IEEE 802.11x WLAN technology that will be deployed on a widespread commercial basis. IEEE 802.11n WLAN technology is expected to provide a combination of range, throughput rate, and security that will be attractive, but will pose similar transitional issues as noted previously with adoption into the standard products of the bus AVL systems integrators.
- Security is essential because agencies will directly interface the garage WLAN network with the agency LAN, with key considerations being the technical approach to firewalls, encryption, and authentication.
- Communications and power cabling to the WLAN access points are key issues, especially if there is a large number of access points to cover an extensive vehicle storage area. As discussed previously, mesh networking technology on a garage-level scale for the WLAN access points network can be considered as a method to avoid the need to run cabling to the more challenging garage access point locations.
- Agencies must carefully design the access points network and channel configurations to avoid channel interference between access points with overlapping coverage of an area and to address and mitigate WLAN interference sources that may exist from other WLANs operating in the vicinity.

INTEGRATION WITH OTHER SYSTEMS

This section discusses some of the potential for integration between the bus AVL system, as defined for this synthesis, and other systems. These can be for existing or other future systems, including those onboard the vehicle, and those can be installed by the agency or operated by third parties.

Onboard

Video Surveillance

Integrators can link a set of onboard video cameras with an onboard video recorder. The onboard recorder could be interfaced with the VLU by means of SAE J1708 or Ethernet link to allow recording of additional data with each video frame (e.g., GPS location, block/run/route/trip/driver identification, and covert alarm status). This interface could also allow transmission of alarm status data from the onboard recorder to the VLU using the mobile data communications system.

One further area of potential integration is that the onboard video recorder might use the mobile data communications system to send selected video segments. Beyond the use of the garage bulk data transfer system, further mobile video transmission would only typically be viable with a high-data throughput system in place.

Farebox and Smart Card Technology

Most fixed-route vehicles have a farebox, many of which are of the more modern electronic type. With an electronic farebox, the operator needs to login at the beginning of a run, which allows the system to record the run with the fare data and to use the correct fareset. During operation, operators are then supposed to press a button on the farebox at the end of each trip of the run, so that the system can use this run segmentation data to allocate the fares collected to each trip.

Modern fareboxes can be interfaced with the VLU by means of the SAE J1708 link. Once the operator has logged into the VLU using the MDT, the system can use these data to simultaneously login the farebox. As the VLU automatically monitors the completion of each trip, this segmentation data can also be automatically provided to the farebox. This interface could also allow transmission of alarm status data from the farebox from the VLU using the mobile data communications system. One further area of potential integration is that the farebox might use the mobile data communications system to send its accumulated revenue data.

Farebox integration is not yet widely implemented in bus AVL systems. In the survey responses to Question 6, 21% of the respondents indicated that farebox integration was a feature of their AVL system, with the breakdown by time period increasing from 3% installed in 1998–2000, to 9% in 2001–2003, and to 9% in 2004 or later. The incorporation of this feature continues to increase. In the survey responses to Question 5, 19% of the responses for agencies currently enhancing an existing AVL system indicated that farebox integration was included in the enhancements.

Some agencies have begun to accept fare payment through a smart card period pass or stored value card, in addition to the acceptance of cash (and in some cases magnetic stripe fare media) by means of the farebox. Some smart card readers are integrated into the farebox, and in other cases the reader is a stand-alone device. If the stand-alone is used, it would need to be separately integrated with the VLU.

Headsigns

Most fixed-route vehicles have a headsign (exterior destination sign at the head of the vehicle), many of which are of the more modern electronic type. With an electronic headsign, the operator needs to log in to the headsign controller at the beginning of a run, which allows the correct destination to be displayed for the initial trip. During operation, operators are then supposed to press a button on the headsign controller at the end of each trip of the run, so that the destination is updated.

Systems can interface modern headsigns with the VLU by means of the SAE J1708 link. Once the operator has logged into the VLU using the MDT, it can use these data to simultaneously log in the headsign. As the onboard AVL system automatically detects the completion of each trip, it can provide this update to the headsign. This interface could also allow transmission of alarm status data from the headsign to the VLU using the mobile data communications system.

Headsign integration is not yet widely implemented in bus AVL systems. In the survey responses to Question 6, 28% of the respondents indicated that headsign integration was a feature of their AVL system, with the breakdown by time period increasing from 3% installed in 1997 or earlier, to 6% in 1998–2000, to 6% in 2001–2003, and to 16% in 2004 or later (some agencies installed in multiple time periods). The incorporation of this feature continues to increase. In the survey responses to Question 5, 25% of the responses for agencies currently enhancing an existing AVL system indicated that headsign integration was included in the enhancements.

Agency Central Systems

Fixed-Route Scheduling Software

This software is used by an agency to enter its timepoint locations, stop locations, trip patterns, and running times, and to provide computer assistance with defining routes, trips, interlining, blocks (the daily work of a vehicle), runs (the daily work of an operator) and rosters (multi-day operator work packages). These together constitute the scheduling of the fixed-route service.

The onboard VLU of the bus AVL system requires the schedule and route data for all runs. Schedule data typically consist of the schedule arrival or departure time for each timepoint. When an operator uses the MDT to log into a run, the VLU can then use these data together with the ongoing GPS receiver location data to track route and schedule adherence.

Agencies typically update their schedules every 3 to 6 months. Integration between the AVL system and fixed-route scheduling is needed to support transferring run schedule data into the AVL system. The fixed-route scheduling software needs to create an export file, which can in turn be imported by the AVL system.

In systems with a garage bulk data transfer WLAN, buses routinely check that they are carrying the most up-to-date schedule files and download the updated file when needed. In systems without garage WLAN, the system may download schedule updates in fragments over the wide-area mobile data system or use a manual procedure with physical memory media (i.e., memory card or stick).

The number of AVL systems with WLAN bulk data transfer capability is increasing. In the survey responses to Question 6, 41% of the responses indicated that this was a feature of their AVL system—with the breakdown by time period increasing from 9% installed in 1998–2000, to 13% in 2001–2003, and to 19% in 2004 or later. In the survey responses to Question 5, 31% of the responses for agencies currently enhancing an existing AVL system indicated that WLAN integration was included in the enhancements.

There are many older systems still using physical memory media. These older systems work so an upgrade is not essential, but many agencies would like to avoid the time needed to physically visit each bus with the memory media. As discussed in the section about garage bulk data transfer communications, agencies must carefully consider network security when setting up a garage WLAN.

If an agency does not have such fixed-route scheduling software, the schedule data periodically required by the onboard VLUs will somehow need to be created. Therefore, the process of getting the required data into the onboard VLUs will be facilitated by implementing such software.

Garage Operations Software

This software helps facilitate and track the assignment of vehicles to blocks and of operators to runs (and thus the assignment of operators to vehicles and pullout and mid-block relief points). The planned operator assignments to runs are typically determined from the periodic "bid" process where operators select their work assignments from the schedule rosters (i.e., usually on the basis of seniority). However, there are ongoing adjustments needed for vacations and absences. Available vehicles and their locations are monitored as the basis for their assignments. There are various other complexities to garage operations that such software assists with, but these are not our primary subject.

Not every agency uses this type of software, but if they do there are opportunities for integration with bus AVL systems. Rather than requiring the operator to log in to their run assignment directly on the MDT, the login can be with the operator number alone. The systems can send the operator number to the garage operations software, which can respond with the correct run assignment. This can reduce the chance to the operator logging into a valid yet incorrect run, which would result in the route and schedule adherence monitoring being on an incorrect basis until this was noticed and the run assignment corrected.

Paratransit Scheduling and Dispatch Software

This type of software is used to support paratransit operations. Typically, it is used to enter individual trip bookings, create run schedule manifests, enter trip completion data, and create invoices and reports. Integrating mobile data communications and MDTs with this software creates opportunities to further enhance operations. The systems can schedule same-day trip bookings using current vehicle locations and update vehicle manifests during the run. Trip completion data are retrieved from the vehicles in real time.

Real-Time Traveler Information Systems

A bus AVL system can use fleet schedule adherence and/or location data to develop real-time predictions for bus arrival times at stops. Agencies can use these predictions as an additional source of information for various types of customer information systems. DMS at selected stops, used to display predicted arrival times for the next bus(es), have been treated as an optional part of an AVL system for the purposes of this synthesis.

However, agencies can add additional real-time traveler information capabilities as an external system that is integrated with the AVL system. In particular, IVR telephone information systems and website applications can incorporate this prediction information. In these systems, the user needs to locate or navigate to the stop of interest to receive the predictions. In an IVR system, this involves using a sequence of voice-based menus (or a stop identification number shortcut) to retrieve spoken predictions, whereas in a website application the predictions can be shown once the user clicks on (or hovers the mouse over) the stop. With a website application, there is the additional option to display vehicle locations.

Timekeeping and Payroll

Although not essential, there can be integration with the agency timekeeping and payroll system. The system can provide actual pull-out and pull-in times for runs as part of the basis for recording time worked and payroll for operators.

Maintenance Management

Bus AVL can be interfaced in various ways with a maintenance management system. The fundamental role of the maintenance management system is to schedule and track preventative maintenance and repairs.

A bus AVL system can use the mobile data communications system to automatically provide current mileage data, in particular on a daily basis as the vehicle pulls in. The odometer interface to the VLU is typically not an adequate source for these data, because this interface just provides to the VLU to odometer pulses (i.e., mileage accumulated) since the login. The mileage source for the maintenance management system needs to be the overall accumulated mileage to date for the vehicle, which requires interface with an additional device for this purpose (e.g., a digital hub odometer). Such a device is sometimes also equipped to provide additional accumulated data of maintenance interest, such as operating hours or idling hours.

Many recent vintage buses are equipped with electronic control modules for major vehicle subsystems, which can continuously record a wide variety of operating parameters (e.g., temperature and pressure). The challenge is to select which parameters to record for end-of-run collection and/or transmit in real time. This depends on the data available from the vehicle equipment, the capabilities of the maintenance management system, the storage capacity of the onboard system, and the transmission capacity of the mobile data communications system.

Data Warehouse Software

This generally refers to a relational database management and reporting system that supports the overall needs of an organization, providing consolidated access to the databases of multiple software applications. Another advantage of a data warehouse can be that individual software applications can share information with multiple other applications, while only needing to be interfaced with the data warehouse.

Geographic Information Systems (GIS)

GIS allows for map display and for geographically oriented data to be displayed as additional layers on a map. The map display of fleet location and status is an integral part of a bus AVL system, and the agency GIS system is commonly the source of this map (allowing the agency to maintain only a single GIS map source). The system can expect its data (e.g., APC stop counts and maintenance data) for geographic visualization as part of the overall agency GIS.

External Central Systems

In addition to the other systems operated by the transit agency, the agency can establish additional interfaces to support information sharing with other public agencies as well as with the private sector. The other public-sector agencies could include other regional transportation agencies (e.g., real-time travel speeds data as an indicator of current traffic conditions to the local traffic management authority and transit information for 511 transportation telephone information systems).

Private-sector collaboration is becoming of increasing interest for providing traveler information systems. In addition to DMS, IVR, and website information services that might be made available directly by the transit agency, various private-sector interests are emerging to use information that transit agencies release even more broadly available to the public.

EMERGING TRENDS

This section has highlighted several emerging trends whose importance is expected to continue to increase:

- Agency-wide data warehousing is expected to become more prevalent and used with increasing effectiveness. The power of the underlying database management and reporting tools will continue to increase, and agencies will gain in both experience and expertise. These technologies will enable an increasing use of "dashboards," which are real-time graphical displays of key fleet performance indicators designed for quick comprehension at the executive management level.
- Broadband mobile data communications is expected to become increasingly available, powerful, and cost-effective relative to radio-based mobile data communications. Key drivers for this will be continuing advances in cellular data services and the emergence of mobile data services leveraging mobile WiMAX technology. The current generation of bus AVL systems has geared its capabilities to require real-time information exchange consistent with radio-based mobile data systems. As more agencies have broadband mobile data available, bus AVL systems will evolve to increasingly incorporate features that take advantage of the new opportunities for the real-time exchange of larger amounts of information between the central and onboard systems.
- Mobile access and location-based services will continue to increase in importance for traveler information services. Many customers can already use mobile personal devices to access telephone information systems and website applications. The number of customers with access to such devices, and the experience and willingness to use them, should continue to increase. This should in turn make it more common for traveler information systems to support and even focus on mobile access. A related development is location-based services, as mobile devices increasingly incorporate relatively accurate real-time device location. This creates the opportunity for the traveler information to be customized to the current location. For example, a current research project is considering technology that would allow a GPS-enabled cell phone to alert the traveler as they approach the stop where their trip itinerary would require them to alight the bus (S. Barbeau, Center for Urban Transportation Research, personal communication, Jan. 11, 2007).

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APPENDIX C

Systems Engineering Process

This section offers an overall approach to selecting and acquiring advanced technology systems, sometimes referred to as the "systems" approach. Its advantages include:

- Being fundamentally driven by the needs of the organization, rather than by the pursuit of technology for the sake of novelty or change as an end in itself;
- Supporting systems integrator selection and project acceptance on the basis of demonstrating agreed functional and performance requirements; and
- Establishing a "feedback loop," where at the conclusion of technology implementation the process can begin anew of reassessing whether further needs remain to be addressed with technologies available at that time.

NEEDS AND TECHNOLOGY ASSESSMENT

The process should begin with a fundamental assessment in which the agency identifies the need to improve certain parts of its service effectiveness or its underlying business processes. The foundation for Intelligent Transportation Systems program development should be that implementing advanced technology could help address those business needs. Another important step is to develop a consensus within the agency on the relative priority of these needs, which will be used to help establish the overall sequence of projects and implementation schedule.

In parallel with the needs assessment, the agency should review available and proven technologies that could be effectively used to enhance transit operations. There are numerous reference sources to use as a starting point [e.g., the Advanced Public Transportation Systems state-of-the-art report (*C1*)]. However, the technology landscape is constantly evolving, including not just the available technologies, but also their current capabilities, how they can be used for transit, and the extent of the experience with their use in revenue service. It is important that agencies acquire a current technology assessment. In addition to identifying potentially useful proven technologies and how to apply these technologies to transit, the technology assessment should also identify the general benefits and costs and organizational impacts (e.g., staffing, training, and organization structure).

Agencies now realize that it is important to build a knowledge base for which technologies have been proven in service and what needs these technologies have been able to address for transit agencies. Many agencies have involved an experienced consultant beginning at this stage in the process, because they have both the direct experience with the actual functional capabilities of the proven and commercially available automatic vehicle location (AVL) systems and the understanding of how other agencies have used these systems. Another useful tool at this stage is a peer review, conducting discussions and site visits with similar agencies that have already deployed or are in the process of deploying an AVL system.

PROJECTS DEFINITION AND IMPLEMENTATION PLAN

Agencies can identify high-priority needs for which proven technology solutions exist. They can define a set of technology deployment projects that address these needs. It is important to structure these projects into a transit technology implementation plan, providing the order in which agencies will deploy the projects and the anticipated timing of the deployments. In addition to a bus AVL system, the plan could include a variety of other transit technology projects.

One important factor in defining the project sequence should be the relative priority of the needs that the projects are addressing (i.e., it would be logical to first pursue those projects that address the highest priority needs). However, other considerations need to be taken into account.

- In some cases, certain projects might need to be in place to form part of the infrastructure that supports pursuing another project. For example, an AVL system project might address needs considered of higher priority than the needs being addressed by a fixed-route scheduling software project. However, the agency may need to deploy scheduling software first because it forms part of the infrastructure needed for the AVL deployment.
- A certain project that addresses a high-priority need might require the use of a technology that is deemed relatively immature or that is undergoing extremely rapid change. The agency may want to delay deployment until the technology is more stable.

One important factor for agencies to consider in planning the expected timing of the deployments is the expected availability of capital and operating funding. In some cases, constrained funding could suggest that some of the projects that address lower priority needs should not be included in the implementation plan (although having identified the purpose for and anticipated benefits from further investments may assist the agency in pursuing the additional funding needed to incorporate additional projects into the implementation plan). Also, the timing of future expected funding available may constrain the pace at which project implementation is planned.

Other important considerations that agencies should consider in planning the timing for implementing the project sequence include the following:

- Each project requires a sequence of design, procurement, implementation, and testing activities, and it is important to incorporate realistic timeframes for this sequence into the implementation plan.
- Introducing the new technologies can have various organizational impacts to which agency staff will need to adapt. Some agencies choose to deploy a new project after a time period during which staff can adapt to the impacts of the prior project. Agencies can include explicit timeframes for staff training and adjustment in the sequence of activities for each project.

Following the implementation plan sequence, the agency can pursue the deployment of individual projects. The initial step for agency staff with each project is to secure both procurement approval from their agency and any external funding sources to be used for the procurement. It is essential at this point that the agency recruit a "champion" from senior management, if such a person has not been involved in the transit technology development program from the outset, to spearhead the effort to secure agency approval of the implementation plan. For example, at Capital Metro in Austin, Texas, the project champion for the current AVL system implementation is the head of Operations, the department that will be the primary user and beneficiary of the system.

The project champion would take a lead role in securing a consensus with other members of agency senior management, for the projects, deployment sequence, and the general timeline. The benefit/cost justification for the individual projects is usually a key feature in validating the implementation plan. Another important role for the project champion is to lead the effort to secure agency investment in staff resources (e.g., retraining and hiring) needed to achieve the benefits available from the projects.

PROCUREMENT OF INDIVIDUAL PROJECTS

Transit agencies require a competitive procurement process. A Request for Proposals (RFP) process is usually preferable for systems procurements, because agencies need to consider many factors other than price in selecting a systems integrator that will provide the best value solution.

A key element in an effective RFP-based procurement is incorporating a thorough specification with functional/performance requirements. This in essence means that the specification defines what the system will be able to do rather than how the system will accomplish these functions. A functional/performance specification is important to preserve maximum competition in the procurement process, because there is a limited pool of qualified vendors for these systems that have differentiated their products by using distinct product designs. A strong functional/performance specification has the characteristic of using requirements that are specific enough. When a proposer has offered to comply, the requirement wording should enable performing acceptance testing to verify that the implemented system has addressed the requirement.

However, the specification should avoid whenever possible prescribing how the system will operate (as opposed to what the system will be able to do). Because a functional requirement can be accomplished in multiple ways, a specification that requires a specific design may be calling for a design that some or possibly even all of the vendors do not use in their proven product (when one or more of the commercially available designs might have addressed the functionality performance that the agency needs). Another critical difficulty with a prescriptive specification is that although the required design may well represent the state of the practice while the specification was being prepared, by the time the procurement has been completed and the implementation is underway there may be newer and superior approaches proven and available from the selected systems integrator (technology evolves rapidly).

Some agencies have also used a Request for Information (RFI) as a useful initial step before issuing an RFP. An ideal time for an RFI is after the agency prepares the draft functional specifications. Potential vendors are invited to comment on the specifications, and if the responses made clear that a certain capability the agency needs might unduly limit the number of competitive vendors, the agency might opt to delete that requirement from the specification or change it to an option. Similar "pre-RFP" consultation with vendors can be used during the technology assessment activity mentioned earlier, as useful feedback for drafting the specifications. For example, TriMet in Portland, Oregon, made use of RFI vendor consultations before issuing the RFP in its procurement process. The "pre-RFP" consultation stage is often coupled with site visits to other agencies that have recently implemented an AVL system and are considered comparable (e.g., fleet size and modes).

There is an inherent challenge in finalizing specifications using input from potential vendors (e.g., RFI feedback, vendor presentations, and discussions at trade shows). Vendors have an underlying interest in attempting to influence the specifications to include requirements that they believe they will be better able to address than their competitors. In other words, it is in the interest of the potential vendors to if possible influence the process to limit the range of competition in the eventual procurement. This is entirely the opposite of the interests of the agency. It can help agencies to have the assistance of an experienced consultant, because they are aware of the actual functional capabilities of the various vendor systems through having worked with other agencies on recent deployments.

An agency evaluation committee needs to evaluate proposals relative to the evaluation criteria identified in the RFP. Based on the evaluation findings, the committee can identify those proposals in the competitive range for even more detailed evaluation. This further evaluation often involves clarification questions and interviews with proposers and, in some cases, site visits with other agencies that have recently implemented a similar system from the contending proposers. Often, the proposers are also asked to submit a Best and Final Offer. Consultant assistance can also be helpful at this stage. Agency staff may not have a comparable technical background to vendor staff, and consultant assistance can help eliminate any vendor advantage in the discussions.

At the end of this process, the evaluation committee will need to reach consensus on the award recommendation; this recommendation typically needs to be translated into the formal selection of the proposal by the agency (e.g., by the Board). At the conclusion of this selection process, agency staff awards a contract that obligates the vendor to the price and other commitments made through the entire proposal process.

Depending on the extent to which the agency has previously undertaken systems procurements, there is some potential for resistance from the agency procurement department to aspects of the process that are considered unconventional. These aspects can include those elements that differ from the conventional procurement approach used for items traditionally purchased by transit agencies (e.g., vehicles), such as a functional/performance specification, the role of non-price criteria in evaluation, and pre-award discussions with proposers and other transit agencies. Initial peer review can be effective, because it allows procurement staff to learn of how their peers at agencies that have previously implemented the system now believe that these approaches are considered effective and even essential for this type of procurement.

IMPLEMENTATION MANAGEMENT

The agency purchase process is far from completed when the contract is first awarded. Implementation management is a substantial undertaking that is critical to the long-term success of the project once it is brought into revenue service. Focusing on AVL systems in particular:

- The agency will need extensive internal coordination between agency business units:
  - The systems integrator will need to gather significant input and configuration data for initial system implementation. The gathering of the required input data will involve representatives from diverse parts of the agency, as will decisions about how to configure the system.
  - Extensive internal coordination will also be needed to support the logistics of the physical installations in facilities and vehicles, and the reconfiguration of existing software and networks being integrated with the new system.
  - This requirement for extensive internal coordination is often a significant challenge for a transit agency, because the various business units are not often required to collaborate in this manner. Mechanisms to require and facilitate such collaboration sometimes do not exist or are rarely used. The involvement of a neutral third party, such as a consultant, can be useful. It is also essential that senior management communicate a vision for the end results intended from the technology implementation plan, coupled with clear direction on collaborative procedures that are required.
  - The evident commitment of senior management to the project and the leadership of a project champion are important steps to convey that these information gathering and coordination activities are essential. The project champion will typically be a member of the senior management team at the agency and will not have sufficient availability to directly coordinate these activities. It is common for the agency to assign one or more agency staff with project manager responsibility for AVL system implementation (with the backing of the project champion), coupled with consultant support.
- There is a general need to hold the vendor accountable to implement a system that demonstrates the functional and performance capabilities that were committed to in the contract.
  - A preparatory design review process before system installation is advisable. The systems integrator uses this process to build a consensus with the agency about the system details. This process should include explicit discussion about how the installed system will address each requirement.
  - The agency and the systems integrator must agree in advance on the formal acceptance test procedures. These procedures serve to demonstrate each contract requirement and commonly involve multiple test stages and steps in the implementation process (e.g., pre-installation, installed in a small portion of the fleet, or at full fleet installation). Consultant assistance can be useful in helping the agency to verify that test procedures proposed by the systems integrator are complete and adequate and that the allocation of test procedures to the various testing stages is appropriate.

EVALUATION

Once the agency has accepted the contract implementation for an individual project, it is important that it evaluates the impact of the project. In the case of an AVL system it is best to do this evaluation long enough after the system has entered revenue service that its users have become accustomed enough to its use that they are more comfortable and have started to learn how to best take advantage of the new capabilities available. It is also useful that an independent entity from the agency leads the evaluation effort, such as was the case with evaluation of the TriMet AVL system in Portland, Oregon, and the potential uses for its data (led by researchers from Portland State University, as discussed in chapter two).

The evaluation can have at least two distinct purposes:

- Evaluation can provide evidence to the agency and external funding sources about the benefits and costs it is experiencing.
  - If the project is living up to expectations, this provides project sponsors with evidence of the value of the decisions and investments they made. This can help enhance the prospects of gaining future funding for additional projects (e.g., upcoming projects in the overall technology implementation plan).
  - If the project results are not yet living up to expectations, it may be that the agency needs to take additional steps to adapt (e.g., procedures or organizational structure) practices to best build on the established successes of the system and more fully leverage its potential. The evaluation findings could provide the motivation to investigate and implement such needed adaptation.
- Evaluation can also help identify whether the resulting changes in agency needs warrant a reassessment of the needs and technology, and thus any evolution in the implementation plan.

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Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation