Improving Public Transportation Technology Implementations and Anticipating Emerging Technologies

DETAILS

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TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 84

e-Transit: Electronic Business Strategies for Public Transportation

Volume 8

Improving Public Transportation Technology Implementations and Anticipating Emerging Technologies

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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 Urban Mass Transportation Administration—now 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 Academies, 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.

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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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FOREWORD

By Gwen Chisholm Smith
Staff Officer
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TCRP Report 84: e-Transit: Electronic Business Strategies for Public Transportation documents principles, techniques, and strategies that are used in electronic business strategies for public transportation. *TCRP Report 84* is being published in multiple volumes; *Volume 8*: *Improving Public Transportation Technology Implementations and Anticipating Emerging Technologies* summarizes the value of current technologies used in public transportation, describes methods for improving the success of technology implementation, and identifies five promising emerging technologies with application for transit agencies. This report may be used specifically by chief executive officers (CEOs) and chief information officers (CIOs) of transit agencies, transit managers, program and project managers, intelligent transportation systems (ITS) professionals, and the public transportation industry in general.

New information and communication technologies are revolutionizing the way services are delivered and organizations are structured. Electronic business processes change the ways organizations operate and conduct business. Opportunities to lower operations and maintenance costs and improve efficiency have changed relationships between transit agencies and their suppliers and customers, and electronic business processes are likely to change industry structures in the long term.

The declining costs of communications, data storage, and data retrieval are accelerating the opportunities spawned by the Internet and other information and communications technologies. Choosing and sequencing investments in technologies, processes, and people to reduce costs and increase productivity present challenges to the transit manager, who must weigh the costs, benefits, and risks of changing the ways services are delivered. To assist in meeting such challenges, TCRP Project J-9 produces a multiple-volume series under *TCRP Report 84.* The research program identifies, develops, and provides flexible, ongoing, quick-response research designed to bring electronic business strategies to public transportation and mobility management.

Improving Public Transportation Technology Implementations and Anticipating Emerging Technologies is the eighth volume in the *TCRP Report 84* multiple-volume series. Battelle, in association with TranSystems, Matthew Coogan, and E-Squared Engineering, reviewed literature, trends, and developments of the past few years related to public transportation and technological advancements. Also, the research team conducted 16 interviews with representatives from both the United States and abroad to determine the extent to which transit agencies worldwide are using various types of information technologies. The research team obtained information on the experiences of transportation providers that have deployed newer technologies, the range of objectives transit agencies have for using current and near-term technologies, and the promises these technologies may hold for transportation operations and the people they serve. In addition, the researchers conducted a focus group that included transit CEOs, CIOs, and senior-level technology personnel from U.S. public transportation agencies to discuss obstacles that impede the adoption of current and near-term information technologies in public transportation and mobility services. Finally, the researchers describe five emerging technologies, how they might be applied, the range of costs, and the benefits of each.

Volumes issued under *TCRP Report 84* may be found on the TRB website at http://www.trb.org/news/blurb_browse.asp?id=1. Click on "Transit Cooperative Research Program" under the "Project Reports" heading.)

CONTENTS

SUMMARY

Improving Public Transportation Technology Implementations and Anticipating Emerging Technologies

Study Purpose and Objectives

The purpose of this study is two-fold: (1) to identify the steps that must be taken—by both individual transit agencies and the transit industry—to improve technology implementations; and (2) to promote consideration of emerging technologies by identifying several developing technologies that have great potential for the transit industry.

This study was motivated by the fact that, despite a number of individual success stories, public transportation in the United States has struggled to take full advantage of advanced technologies. Public transportation lags behind the commercial freight and air passenger transport industries. Some transit technology implementations have failed, and many don't perform as they can (for example, technology implementations that fail to integrate various technology systems within an agency). Further, few transit agencies are able, in any systematic manner, to anticipate or plan for the adoption of emerging technologies.

Many members of the transit industry feel that the industry has been stuck in a sort of quagmire for a number of years. Many transit agencies understand that they have struggled with technology, are aware of many specific obstacles they face, and even recognize a number of the technology "best practices," but they somehow are unable to significantly improve their technology implementations. The solutions are not easy to implement, but this study identifies the key strategies and actions needed to move transit to the next level.

The remainder of this summary highlights the major findings of the study and guidance based on these findings. Specifics, including best practices, are presented in the full report.

Methodology

This study featured three primary research methods: (1) a review of the public transportation and technology literature; (2) interviews with representatives from U.S. public transportation agencies, international public transportation agencies and transportation research organizations, and a U.S. commercial package delivery service; and (3) a day-long facilitated focus group with general managers (GMs)/chief executive officers (CEOs) and senior-level technology personnel from several U.S. public transportation agencies.

Conclusions

Study conclusions are organized into three main categories. The first category summarizes what is understood about the value of current technologies in public transportation. The second and third categories correspond to the two primary purposes of this study: improving transit technology implementations and identification of a few promising emerging technologies.

The Value of Technology

Study conclusions about the value of current technology in public transportation are the following:

- There is a wide range of mature, commercially available technologies applicable to every major activity undertaken by transit agencies, and these technologies have the potential to generate significant efficiency and service quality benefits.
- Anecdotal evidence suggests that many benefits have been realized by U.S. public transportation agencies from implementing advanced technologies, but there is a very limited amount of reliable and transferable quantitative data on benefits. More formal, post-deployment evaluation of observed benefits is needed.
- Despite great promise and some successes, the overall performance of technology in the U.S. transit industry has fallen far short of its potential, for three reasons:
  - The processes used to deploy technology have not always addressed the most important issues—institutional and organizational issues.
  - Transit agencies have not taken full advantage of the technologies they deploy, e.g., analyzing data generated by vehicle tracking systems and using it to restructure their services.
  - Few transit agencies have integrated their deployed technologies to any significant degree. Rather, most systems are implemented and operated separately, in a stand-alone fashion, and, consequently, synergistic benefits are not realized.
- Many of the most progressive of U.S. transit agencies are focused on replacing, upgrading, and/or integrating very mature technologies, such as vehicle tracking, rather than on identifying emerging technology applications. Private companies are significantly more focused on anticipating and adopting emerging technologies.
- There is a continuum of approaches to technology deployment among transit agencies. Most U.S. agencies have stand-alone technology systems that reflect the objectives of individual business units within the agency. The most advanced U.S. transit agencies are beginning to integrate technologies and base investments on broader, agency-wide business objectives. Advanced international transit agencies have made more progress in integrating their technology systems. Also, their investments are more often driven by agency-wide objectives, and, increasingly, on regional or even national mobility considerations.

Improving Transit Technology Implementation

Study conclusions about improving transit technology implementation in public transportation are the following:

- There are a number of serious obstacles to successful deployment. Many transit agencies are aware of these obstacles, but still struggle to overcome them. Even the most progressive and successful agencies remain quite challenged by these obstacles.
- The most challenging obstacles are institutional and organizational, including a shortage of visionary leaders and organizational resistance to change. There are a number of specific strategies and actions ("best practices") that have been proven successful by transit agencies in addressing technology obstacles. Three of the most critical strategies are enterprise architecture planning (EAP), systems engineering (SE), and change management.
- EAP and SE are techniques that are vital to technology success and have been widely validated outside the transit industry. However, these techniques are fully understood and effectively practiced by only a few transit agencies. Of the two strategies, EAP is more overarching and comes first sequentially. EAP focuses on the overall business goals and needs

of the organization and providing the context and basis for technology investments. SE is a structured, rigorous process utilized to develop and implement specific technology projects, that is, to implement the strategy identified through EAP. Both EAP and SE help maximize the benefits and cost-effectiveness of technology investments. The success of large, complex transit technology implementations cannot significantly improve if transit agencies do not master these techniques. A considerable amount of general information is available describing how to implement EAP and SE (although this information does not necessarily target a transit audience).

- Despite the benefits of EAP and SE—both provide returns well in excess of their additional expense—widespread penetration and application of EAP and SE will constitute nothing less than a revolution in U.S. public transportation. First, these techniques, although scalable to fit the size and complexity of a project, are much more resource intensive and demanding than the inadequate methods that are typically utilized. Therefore, not only must the skills be present to understand and apply EAP and SE, agency leadership must buy into the value of these techniques and make the resources available for technical staff to learn and exercise the techniques. Second, many transit agencies are still in the earliest stages relative to EAP and SE, so they are either not fully aware of these techniques or have not accepted that they must utilize them.
- In order to fully succeed, any significant technology investment must be accompanied by a robust and inclusive change management strategy. Change management includes various types of stakeholder involvement techniques and aims to promote awareness and understanding, manage expectations, ensure readiness, and promote acceptance. Change management is the most important tool for addressing the greatest obstacles to technology investment—institutional and organizational challenges. The fact that the vast majority of technology project failures stem from "people" issues rather than technical issues is widely accepted. Change management targets the "people" aspect of technology deployments.
- In the general IT arena, the positive return on investment (ROI) of change management, methods for carrying out change management, and the need for change management have been well documented. What's preventing more transit agencies from practicing these techniques appears to be an underappreciation of the necessity of change management and resource constraints.
- Comprehensive ROI analyses are vital for a number of reasons. These analyses promote good investment decisions, are useful in building support for investments, and, as a consequence of estimating benefits, help transit agencies visualize how they must utilize the technology in order to realize benefits. Good ROI analyses also provide—for individual agencies and the industry—a good baseline for before-after analyses.
- In addition to the techniques of EAP, SE, and change management, there are many methods and actions that have been proven successful in improving technology implementations. These best practices cut across all aspects of agency operations, and all stages of technology implementation, from institutional to technical, and from procurement to operations and maintenance. The recommended best practices are described in detail in Chapter 2 of the full report.
- All the greatest advice on "best practices" will not ultimately make the difference for transit agencies that lack the fundamental, "prerequisite" conditions and capabilities necessary to carry out the best practices. Prerequisites include the following:
  - Agency *leadership* (CEO, GM, and/or board) that understands and supports technology.
  - A *vision* for how technology will permeate and benefit the agency. This vision must be directly linked to a phased, realistic *plan* identifying the steps and activities necessary to realize the vision, and that plan must be developed based on input from a very wide range of stakeholders.

  - An *organizational culture* that supports technology and accepts change.
  - A *supportive community* that values transit and supports investments, including technology investments, to improve transit.
  - *Resources* or the ability to get them (e.g., through good grant-writing skills or via partnering).
- The prerequisite issue is a significant problem for transit. Participants in the transit agency leader focus group speculated that half of all U.S. public transportation agencies may lack these prerequisites. As long as these prerequisites are lacking, despite the best of intentions and full access to the best guidance, these agencies are at risk for failed or compromised technology implementations.

Promising Emerging Technologies

Study conclusions about promising emerging technologies in public transportation are the following:

- Although it is not necessary or efficient (to individual agencies and their customers or to the industry overall) to have more than a few pioneering transit agencies on the technology "bleeding edge," more agencies need to move closer to the "leading edge." While the highest short-term priority is helping more transit agencies take better advantage of current technologies, the industry should not neglect the longer-term benefits of improving the industry's tracking and adoption of emerging technologies.
- Emerging technologies in five areas that have high potential for transit include the following.
  - **Hybrid-electric transit buses** will dramatically reduce vehicle emissions when they are more widely in use. (Although hybrid-electric transit buses are already in limited use at a few transit agencies, the dramatic impact of the proliferation of this technology warrants its inclusion as an emerging technology.)
  - Various **nanotechnologies,** technologies engineered on the molecular scale, will make microprocessors smaller and more powerful and enable new and more effective sensors and forms of surveillance. Nanotechnology will improve almost every aspect of transit operations, including enabling increased automation of vehicle operations, ubiquitous real-time exchange of information with customers, and seamless integration of services.
  - **Mechatronics—**the integration of traditional mechanical systems with electronic components and intelligent software control—will greatly increase fuel economy, improve vehicle performance and safety, and streamline maintenance.
  - Advances in **speech recognition** and **language translation** hold the potential to greatly improve the efficiency and effectiveness of transit customer service. Further, these technologies enable the sort of communication necessary to support dramatically more flexible, convenient, and accommodating (for example, to non-English speakers) transit services.
  - **Pervasive wireless communication** describes a future condition when a wide range of mobile, radio-equipped devices—mobile telephones, computers, and various sensors—will be able to form ad hoc communications networks. **Cognitive radio,** one of the methods for forming communications networks, uses smart communications devices to detect and utilize currently unused portions of local radio spectrum that are licensed to other types of devices.
- There are many other emerging technologies that may hold potential for transit. These technologies include "electronic paper" and stretchable silicon that will enable better dis-

plays and sensors; pseudolites and stereo video image processing, which fill global positioning system (GPS) gaps to improve vehicle navigation; artificial intelligence (AI) techniques like Bayesian Machine Learning to facilitate data mining and recognition of customers' patterns and preferences; silicon photonics to increase the speed of communications; quantum cryptography to improve data security; and terahertz radiation applications to improve security and speed communications.

Guidance

Guidance resulting from this study falls into two general categories: the first category includes guidance for individual public transportation agencies and the second category consists of guidance for the public transportation industry in general.

Guidance for Individual Public Transportation Agencies

- **Follow Best Practices.** The overarching guidance for transit agencies is to take the time to read, understand, and employ the many best practices identified in the full study report (see Sections 2.2.2 and 2.2.3).
- **Be Realistic and Consider Prerequisites.** Before contemplating technology investments, make a realistic assessment of the agency's ability to fully and successfully implement the system and operate and maintain it over the long term. That assessment must take into account the crucial roles played by EAP, SE, change management and a rigorous ROI analysis. The agency's ability to carry these activities out or the agency's resources for contracting these activities out and effectively supervising the contractor should be fully considered. For example, assess the knowledge, skills and abilities (KSAs) necessary for agency staff over the course of the entire system life cycle, starting with procurement, moving through operations, and ending with system replacement. If the agency is lacking in any area, focus on establishing those capabilities before moving ahead with deployment.
- **Emphasize Quality over Quantity.** When planning for technology and pursuing specific investments, emphasize quality and sustainability. It is better to provide smaller, fully realized, and lasting improvements than to invest in ambitious systems that cannot be fully integrated within the transit agency or properly maintained over the long term. Doing an exemplary job of meeting important but realistic goals and objectives is a more valid way of distinguishing an agency as a technology leader than competing to implement the most, or the very latest, technologies.
- **Partner.** Support and participate in cooperative efforts to pool expertise and other resources with transit agencies that have similar needs and interests. The developing Applied Transit Technology Center, led by the Utah Transportation Authority (UTA) in partnership with several other transit agencies, is a very promising example. The objective of the Center is to serve as a collaborative effort or consortium among transit agencies to foster the application of technological innovation.

Guidance for the Public Transportation Industry

- **Tailor funding to agency needs and capabilities.** Study results suggest that technology deployment funding can be most effective in transit agencies that have the necessary prerequisites for technology success. For agencies that lack those capabilities and conditions, it would be more effective to provide assistance in developing the prerequisites than to fund low-payoff technology deployment. Assistance in developing the prerequisites would be most helpful if it included training, consensus-building, outreach and education, planning support, and various kinds of technical support. In concert with restricting deployment funding to capable transit agencies, make it easier for agencies not yet ready to deploy to say "no" to available deployment funding: allow them to convert deployment funds into technology technical assistance.

- **Provide more technical assistance and be more aggressive in promoting, and requiring compliance with, established policy and best practices.** Study results suggest that the assistance and guidance provided to transit agencies for SE, EAP, change management, and ROI analysis be increased. It would be best if this increased support was combined with more aggressive oversight and enforcement (raise the level of expectation) of the existing FTA National Intelligent Transportation System (ITS) Architecture Policy on Transit Projects that requires use of an SE analysis. (The term "Intelligent Transportation Systems" refers broadly to a wide range of advanced technologies for surface transportation, including sensors, surveillance, communications, and data processing.) When funding requests are evaluated, it would be useful to give greater consideration to transit agencies' readiness for technology deployment, as evidenced by their treatment of EAP; SE; change management; formal ROI analysis; and formal, post-deployment, quantitative evaluation.
- **Improve dissemination.** It would be useful to enhance and supplement traditional methods for disseminating TCRP study results. An enhanced strategy would be one that recognizes that most practitioners suffer from a great surplus of information and a great deficit of time and energy to process it. An enhanced strategy would include a carefully crafted *message* delivered by a credible, energetic, and trusted *messenger* (an "evangelist") and disseminated using the latest and most effective *mechanisms* (see Section 4.2 for details).
- **Combine dissemination with political and policy arena follow-up.** Even the most effective dissemination of the findings of this study will not be sufficient to solve the fundamental "prerequisite problem" faced by many transit agencies. Some agencies will need more help with the most fundamental challenges. Solving the prerequisite problem will require industry-level action in the political and policy arenas. Efforts should focus on specific actions and policies:
  - Transit must be improved in order to play its necessary role in meeting future transportation challenges.
  - Effective utilization of technology is a vital, primary means of improving transit (rather than just a "good idea if you can afford it"—we cannot afford not to).
  - Technology cannot be effectively exploited without the proper support and resources being provided to transit agencies. The nature of this support should be carefully aligned with each agency's needs. Deployment funding should be restricted to those agencies with demonstrated prerequisites and a commitment to EAP, change management, ROI analysis, SE, and post-deployment evaluation. For agencies lacking the prerequisites and commitments to change management, post-deployment evaluation, and other proven and needed techniques, resources should be provided in the form of technical assistance to establish the prerequisites and other commitments.

CHAPTER 1

Introduction and Research Approach

This report summarizes the results of TCRP Project J-9/ Task 12, "New and Emerging Information Technologies for Public Transportation." Other tasks within TCRP Project J-9, "e-Transit: Electronic Business Strategies for Public Transportation," have considered issues such as the use of the Internet for training and certification and utilization of technology in parts and inventory management. This study focuses on summarizing the value of technologies currently utilized in public transportation, synthesizing recommendations for how transit agencies can best benefit from the application of advanced technologies, and identifying five emerging technologies that hold promise for transit agencies. The intended audience for this study includes individual public transportation agencies and the public transportation industry in general, including FTA and industry associations such as APTA.

This chapter provides an overview of the research study and identifies the scope of this report. Chapters 2 and 3 present the study findings. Findings related to current technologies, including their value and how best to realize that value, are presented in Chapter 2. Findings related to future technologies with high potential for use in public transportation are presented in Chapter 3. Chapter 4 includes a summary and interpretation of findings.

The successful completion of this study is a result of the very high degree of coordination and cooperation between the consultant research team, the TCRP program manager, and the TCRP project panel. Throughout this report, the term "project team" is used to denote these partners.

1.1 Project Overview

1.1.1 Background

Our society is vastly different from what it was just a few decades ago. The pervasiveness of technology has increased access to information and changed the way people work, communicate, and travel. The trend toward globalization has had a dramatic effect, and the challenge to use technology to its fullest is ever present. As a result, many transit agencies face decisions about which technologies are most appropriate for their use.

The Internet and personal information and communication devices as well as on-board vehicle and passenger technologies have revolutionized the way services are delivered and organizations are structured in many industries. Expectations have changed as customers have become accustomed to obtaining new information and services on a real-time basis. Behind the scenes, electronic business processes, real-time vehicle data, and wireless technologies are starting to change the ways that organizations operate and conduct business. Opportunities to lower costs and improve efficiencies have, in some key examples, changed relationships among transit agencies, their suppliers, and customers. Portals for government-to-government and business-to-government marketplaces have started to be offered through diverse organizations. Some transit agencies are offering or are preparing to offer customized itinerary planning and fare-media purchasing as well as real-time passenger information over the Internet.

However, for a variety of reasons, many transit agencies have been slow to adopt new technologies. These reasons include lack of information about new technologies and how they might be adapted to transit needs; lack of funding; fear of public failure in the adoption of new technology and the attendant criticism; lack of knowledge about and expertise in the benefits of technology investments and how to sell these benefits, particularly where benefits are not clearly quantifiable; and impediments posed by agencies' organizational structures, which tend to be hierarchical and command-and-control in nature.

The declining costs of communications, data storage, and data retrieval are accelerating the opportunities for both transit agencies and their customers to take advantage of the benefits of technology. Transit managers, planners, and transportation technology professionals—all of whom must weigh the costs, benefits, and risks of changing the way services are delivered—face challenges to their knowledge bases and skills. There is a need to understand the ground rules for choosing and sequencing investments in technologies, processes, and people to reduce costs and increase productivity.

TCRP's e-Transit research program seeks to identify, develop, and promote research to maximize the benefits of e-commerce and other new technology applications for public transportation and mobility management. The e-Transit research program seeks to develop a road map for transit professionals to understand immediate as well as short- and long-term products and strategies, with an emphasis on quick delivery.

1.1.2 Study Objectives

The objectives of this research are the following:

1. Provide those responsible for public transportation with the best thinking available on technologies and how they might be deployed in the service of public transportation.
2. Provide transit agencies with specific, proven techniques and "best practices" for overcoming the significant obstacles they face in taking full advantage of technologies.
3. Provide information on emerging technologies, identifying five technologies that hold the most promise for public transportation and mobility. (In this research, mobility is defined as the ability and knowledge to travel from one location to another using a multimodal approach, with one of the modes being a public transportation service.)

For purposes of this research, current technologies are understood to be those currently in use in a transportation application, including applications in Asia and Europe; emerging technologies are those that could be implemented in transportation applications within the next 3 to 10 years.

1.1.3 Research Tasks

This study has two major parts. The first part focuses on providing transit agencies with practical, proven techniques for surmounting technology-related challenges. This first part includes documentation of current technologies and their benefits, identification of methods that have been used to build business cases for investing in those technologies, documentation of the obstacles to technology exploitation, and, most importantly, identification of best practices to address those obstacles. The second part of the study focuses on providing transit agencies with a few "promising technologies to watch" to facilitate their consideration of the uses of such technologies.

Midway through this study, TCRP reduced the scope of the emerging technologies portion in order to provide the resources necessary for a thorough treatment of best practices, including greater investigation of techniques such as Enterprise Architecture Planning and Change Management. That reduction in scope eliminated consideration of the more distant emerging technologies—those expected to be available to transit between 11 and 20 years from today (the analysis included in this report considers technologies up to 10 years out)—and hypothetical case studies describing how the high potential emerging technologies might be implemented by various types of agencies.

1.2 Approach

1.2.1 Interviews

Interviews were conducted with technology decision makers from eight U.S. public transportation agencies of varying sizes, seven international public transportation agencies and research organizations, and the United Parcel Service (UPS). In identifying interviewees, the objective was to include only those organizations that have been successful in adopting advanced technologies. This was critical because understanding how to overcome obstacles to technology adoption was a key objective of the interviews. Another objective in selecting interview subjects was to include agencies of varying sizes. International organizations and a commercial organization were included to bring in perspectives from outside the U.S. transportation agency environment. Working with these criteria, a list of interview subjects was developed based on the knowledge of the research team and with input from the TCRP panel members.

Most of the interviews were between 60 and 90 minutes in duration and were completed between February and May 2005. Table 1 lists the organizations and individuals interviewed.

Interview discussions centered on the following four topics:

1. The next steps in the organization's information technology program (i.e., their current design and implementation focus).
2. The organizational structure and processes that have been successfully utilized to identify, plan, implement, and operate advanced technologies, including keys to overcoming obstacles.
3. Promising developing technologies currently being tracked and investigated.
4. Trends and factors that are anticipated to significantly impact future operations, including utilization of technology (e.g., changes in costs or funding and demographic changes).

Table 1. Organizations and individuals interviewed.

Organization	Interviewees
U.S. Public Transportation Agencies	
Ann Arbor Transportation Authority	Greg Cook, Executive Director
Cape Cod Regional Transit Authority	Kirk Dand, General Manager (contracted)
Central Ohio Transit Authority (COTA)	Mark Nawrath, Director of Project Management (no longer with the agency)
Ride On (Montgomery County, MD)	Alfie Steele, Communications Manager
OUTREACH (San Jose, CA)	Kathryn Heatley, President & Chief Executive Officer
King County Metro (Washington State)	Kevin Desmond, General Manager
TriMet (Portland, OR)	Ken Turner, Manager of Operations
Washington Metropolitan Area Transit Authority (WMATA) (Washington, D.C.)	Edward Thomas, Assistant General Manager, Department of Planning and Information Technologies
International Public Transportation Agencies and Research Organizations	
Gothenburg (Sweden) Transit Agency	Anders Kabjorn, Director of Marketing (retired)
Chalmers Institute of Technology (Gothenburg)	Stig Franzen, Professor
Transport Direct (London)	Nick Illsley, Project Director
United Kingdom (UK) Department of Transport	Chris Gibbard, Development Manager
INRETS (Paris)	Guy Bourgeis, Director INRETS (former Director of Strategies for RATP)
Transport for London	Peter Hendy, Managing Director of Surface Transport, and Robert Kiley, Commissioner (part of the interview)
Hong Kong Transit	Tony Yeung, Manager of Operations
Commercial Package Delivery Service	
United Parcel Service (UPS)	Donna Barrett, Technology Public Relations Manager

All of the international interviews were conducted in person; all others were conducted by phone. In the case of the transportation agencies, interviewees were generally individuals with job titles such as general manager (GM), who had a high-level perspective on technology-related issues and an appreciation for overarching issues such as policy, organizational culture, etc. In several cases, additional agency personnel with firsthand technology planning and implementation experience also participated.

1.2.2 Literature Review

A literature review was conducted to identify the value of current technologies, the obstacles associated with deploying technologies, methods of overcoming these obstacles, and the best practices associated with deploying the technologies. Information was obtained from a variety of resources, including TCRP reports, U.S. DOT and other intelligent transportation systems (ITS) evaluation reports, the ITS Cost-Benefit Database, and general information technology literature such as the Massachusetts Institute of Technology (MIT) *Technology Review*. TCRP reports were consulted to identify the issues associated with traveler information systems.[1] The TCRP reports that covered the "new paradigms" research were reviewed to identify the changes that could help transit agencies in overcoming obstacles in technology implementation.[2]

[1] C. L. Schweiger, *TCRP Synthesis 48: Real-Time Bus Arrival Information Systems* (Washington, D.C.: Transportation Research Board of the National Academies, 2003), http://trb.org/publications/tcrp/tcrp_syn_48.pdf; Multisystems, Inc., *TCRP Report 92: Strategies for Improved Traveler Information* (Washington D.C.: Transportation Research Board of the National Academies, 2003), http://gulliver.trb.org/publications/tcrp/tcrp_rpt_92fm.pdf.

[2] Cambridge Systematics Inc., Matthew A. Coogan, Multisystems Inc., Robert F. Wagner Graduate School of Public Service, and TransManagement Inc., *TCRP Report 58: New Paradigms for Local Public Transportation Organizations—Task 5 Report: Opening the Door to Fundamental Change* (Washington, D.C.: Transportation Research Board, National Research Council, 2000), http://gulliver.trb.org/publications/tcrp/tcrp_rpt_58.pdf; R. G. Stanley, Matthew A. Coogan, M. P. Bolton, S. Campbell, and R. Sparrow, *TCRP Report 97: Emerging New Paradigms: A Guide to Fundamental Change in Local Public Transportation Organizations* (Washington, D.C.: Transportation Research Board of the National Academies, 2003), http://gulliver.trb.org/publications/tcrp/tcrp_rpt_97.pdf; Cambridge Systematics Inc., *TCRP Report 53: New Paradigms for Local Public Transportation Organizations—Task 1 Report: Forces and Factors That Require Consideration of New Paradigms* (Washington, D.C.: Transportation Research Board, National Research Council, 1999), http://gulliver.trb.org/publications/tcrp/tcrp_rpt_53.pdf.

Several ITS deployment evaluation reports, such as the Metropolitan Model Deployment Initiative (MMDI) reports and the Northern Virginia Transportation Commission (NVTC) evaluation report, were consulted to study the customer perception of transit ITS.[3] These reports provided an overview of customer acceptance of transit technology. An earlier FTA report was also consulted to study customer acceptance of existing transit technologies.[4] The ITS Cost-Benefit Report and Database were reviewed to study the financial impacts of transit ITS.[5] Several other resources were consulted to identify emerging technologies that may have the potential to improve transit service, operations, management, customer service, and information. Finally, technical papers from several of the most recent ITS America annual meetings and ITS World Congress conferences were reviewed to determine the most recent research and development, and actual efforts related to advancements in transit technology.

1.2.3 Focus Group

A day-long facilitated focus group was conducted with several transit agency chief CEOs, GMs, and information technology (IT) and Planning Department Managers at the Beckman Center in Irvine, California, on August 28, 2006. The purpose of the focus group was to validate and expand upon draft findings related to the value of technologies, methods used to evaluate and demonstrate the rationale for deploying technologies, and best practices for overcoming obstacles to taking full advantage of technologies.

The objective in identifying focus group participants was to keep the size of the group small enough to allow significant interaction among all participants while at the same time sampling a range of opinion from agencies in different geographic regions and of different sizes. The focus was on senior transit leadership because, based on the preliminary findings of Tasks 1 through 4 of TCRP Project J-9/Task 12, the discussion of best practices was expected to center primarily on institutional issues. Members of the TCRP project panel were instrumental in the identification and recruitment of focus group participants. In addition to members of the research team, focus group participants included the following:

- Ron Barnes, GM, Valley Metro East Valley Operations, Veolia Transportation.
- John Inglish, GM, Utah Transit Authority (UTA).
- T. J. Ross, GM, Pace Suburban Bus Service.
- Michael Setzer, CEO/GM, Southwest Ohio Regional Transit Authority.
- Edward Thomas, Assistant GM, Washington Metropolitan Area Transit Authority (WMATA).
- Gwen Chisholm-Smith, TCRP Senior Program Officer.
- Paul Toliver, Former Transit Director, Seattle Metro, and Director, King County Department of Transportation, King County, Washington; currently President of New Age Industries, LLC (Panel Chair).
- Robin Cody, Chief Information Officer and Manager of the Information Technology Department, Bay Area Rapid Transport (BART) (Panel Member).
- Peter Anderson, Chief Information Officer, City of Fort Worth (Panel Member).

Each focus group participant was provided a read-ahead package in advance of the focus group summarizing the purpose and objectives of the project and the preliminary findings related to obstacles to technology deployment. The focus group consisted of four main activities. First, Mr. Toliver, Mr. Cody, and Mr. Thomas gave short presentations highlighting their experiences and lessons learned in implementing advanced technologies. The second activity was a facilitated group discussion of best practices—what works and what doesn't—in areas ranging from institutional to technical. The third activity was a facilitated group discussion of how the results of this study can benefit transit agencies, including consideration of the concept of "prerequisites"—basic conditions and capabilities needed in order to successfully apply more specific, technical best practices—and how to disseminate the results of this study. A summary of the focus group is presented in Appendix A.

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[3] J. Lappin, *Advanced Traveler Information Service (ATIS): What Do ATIS Customers Want?* (Washington, D.C.: Intelligent Transportations Systems Joint Program Office [ITS JPO], U.S. DOT, January 2000), www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/12284.pdf; S. Radin, B. Sen, and J. Lappin, *Advanced Traveler Information Service (ATIS): Private Sector Perceptions and Public Sector Activities* (Washington, D.C.: ITS JPO, U.S. DOT, January 2000), www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/12283.pdf; J. Lappin, *Advanced Traveler Information Service (ATIS): Who are ATIS Customers?* (Washington, D.C.: ITS JPO, U.S. DOT, January 2000), www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/12285.pdf; TranSystems Corporation, *Development of a Continuing Process for Monitoring Performance Data on Transit-Related ITS Investments,* final report of a study conducted for the Northern Virginia Transportation Commission (Arlington, VA: Northern Virginia Transportation Commission, 2003), www.thinkoutsidethecar.org/pdfs/December%202003%20Monitor%20Performance%20its%20Investments.pdf

[4] Battelle Memorial Institute and Multisystems Inc., *Customer Preferences for Transit ATIS: Research Report,* FTA-OH-26-7015-2003.1 (Washington, D.C.: FTA, U.S. DOT, August 8, 2003), http://www.its.dot.gov/transit_dev/atis/ATIS.pdf.

[5] Mitretek Systems, Inc., *Intelligent Transportation Systems Benefits and Costs: 2003 Update* (Washington, D.C.: FHWA, U.S. DOT, May 2003), www.its.dot.gov/jpodocs/repts_te/13772.html.

CHAPTER 2

Findings on Current Technologies

This chapter presents analysis and findings pertaining to current public transportation technologies. These findings fall into three categories: (1) the value of current technologies, (2) recommended strategies and practices for improving the success of technology implementations ("best practices"), and (3) transit agency "prerequisites" for employing best practices. The first section, on the value of technology, includes a description of the technologies, an assessment of the value transit agencies have derived from them, and a discussion of three real-world examples of how agencies have applied state-of-the-art techniques to maximize the value of technologies. The second section, on best practices, identifies both overarching strategies critical to success (Enterprise Architecture Planning, Systems Engineering, and Change Management) as well as specific practices ranging from institutional to technical. The third main section of this chapter, on prerequisites, identifies core capabilities and conditions that must be present within a transit agency to allow it to successfully employ more specific best practices and the implications for agencies lacking those prerequisites.

2.1 Value of Current Technologies

The purpose of this section is to identify current application of technologies to transit, discuss the expected and reported benefits of the technologies, and discuss several actual cases in which agencies have used an exemplary process to plan, procure, and deploy technology. Section 2.1.1 includes brief descriptions of technologies in current use, along with their level of deployment throughout U.S. transit agencies. Section 2.1.2 describes the value of technology throughout the industry. Three main issues that will be discussed in Section 2.1.2 are the following: (1) there is minimal information about the expected benefits of technology deployment and no "baseline" for interpreting the expected benefits of technology deployment; (2) there is little to no assessment of the "real" benefits *after* technology has been deployed; and (3) many technology deployments in the U.S. transit industry have not provided all the benefits that they potentially can. Section 2.1.3 describes the methods and processes of three U.S. transit agencies that have successfully approached technology deployment.

2.1.1 Current Technologies and Their Application

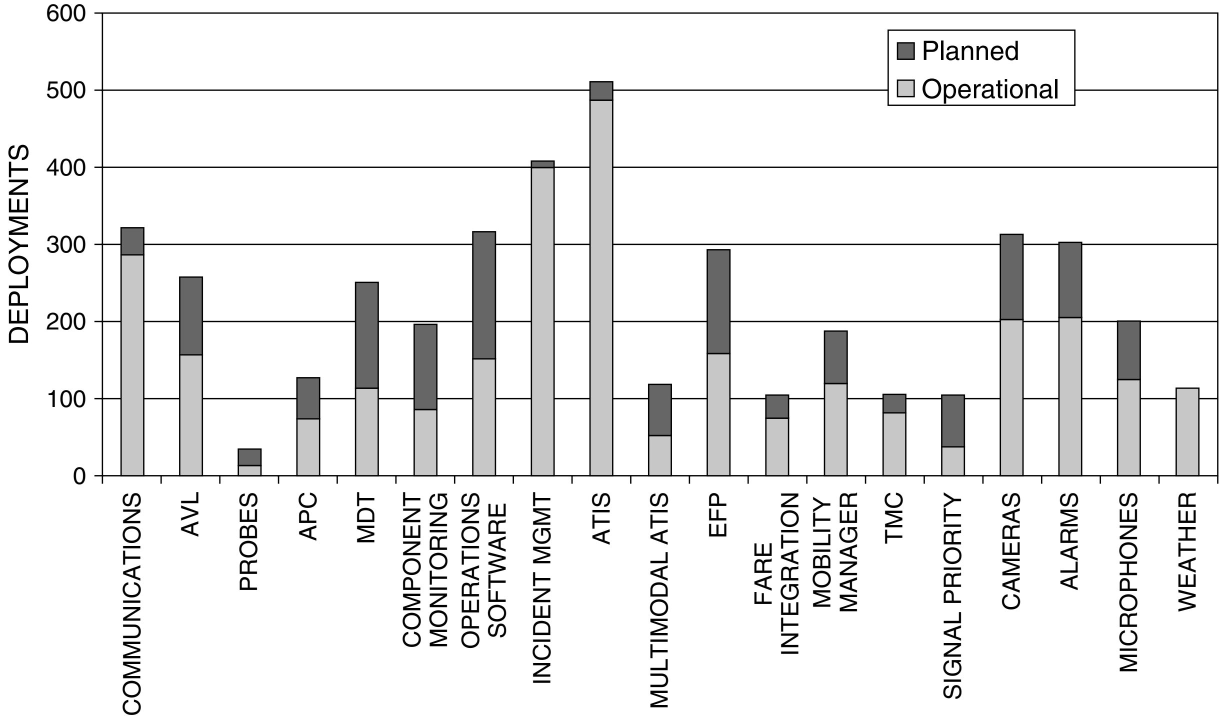
The following subsections provide a brief overview of technologies that are currently deployed at transit agencies in the United States. The technologies can be classified using the following functional categories:

- System integration,
- Fleet management,
- Electronic fare payment (EFP) systems,
- Automated traveler information,
- Transit safety and security,
- Transportation demand management (TDM), and
- Intelligent vehicle systems (IVS).

The technology descriptions in this section incorporate material from *Advanced Public Transportation Systems: The State of the Art—Update 2006.*[6] Information on the deployment status of these ITS technologies across the United States is based on *Advanced Public Transportation Systems Deployment in the United States—Year 2004 Update.*[7] The deployment

[6] M. Hwang, J. Kemp, E. Lerner-Lam, N. Neuerburg, P. Okunieff, *Advanced Public Transportation Systems: The State of the Art—Update 2006*, FTA-NJ-26-7062-06.1, prepared for FTA Office of Mobility Innovation (Washington, D.C.: U.S. DOT, March 30, 2006).

[7] S. Radin, *Advanced Public Transportation Systems Deployment in the United States: Year 2004 Update*, Prepared by the Research and Special Programs Administration/John A. Volpe National Transportation Systems Center for the FTA Office of Mobility Innovation (Washington, D.C.: FTA, U.S. DOT, June 2005), p. 8, www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE//14169_files/14169.pdf.



Notes: A total of 516 transit agencies were surveyed. AVL = automatic vehicle location. APC = autmatic passenger counting. MDT = mobile data terminal. ATIS = advanced traveler information systems. EFP = electronic fare payment. TMC = transportation management center.

Figure 1. Summary of technology deployment.[8]

status was determined based on a survey of agencies included in the National Transit Database. Survey data was collected by the Volpe National Transportation Systems Center (Volpe Center) and Oak Ridge National Laboratory (ORNL). A total of 516 agencies responded to the survey. The surveys were divided into two categories:

- The 78 largest metropolitan areas (jurisdictions with population > 50,000), which accounted for 189 of the 516 respondents
- The remainder of the United States, which accounted for the other 327 respondents.

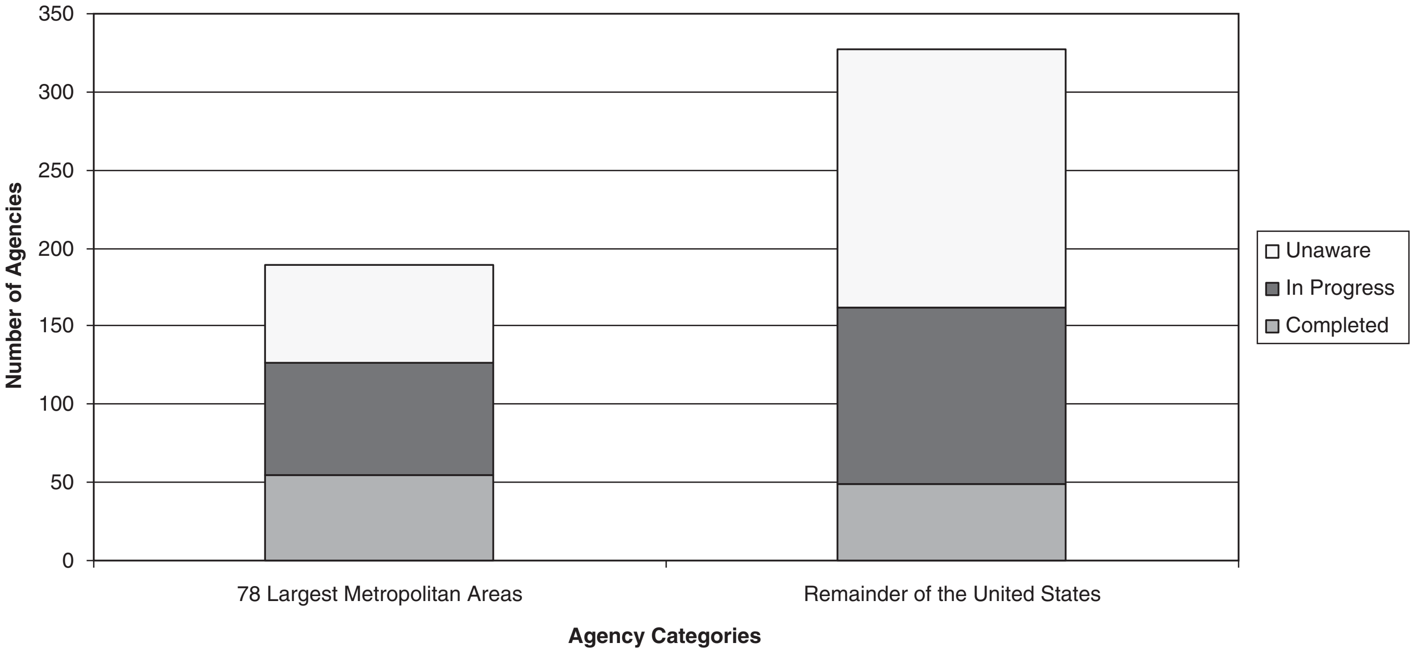
Some caution should be exercised in using the survey results in drawing conclusions relating to the penetration of the most advanced technologies. Survey categories include, or may be interpreted to include by some responding agencies, a very wide range of applications, ranging from older, fairly low-tech to sophisticated, cutting-edge applications. For example, the category "automated transit information" includes the widely deployed, very basic and no-longer state-of-the-art customer information lines that provide only prerecorded information on fares and schedules. This same category includes the much more sophisticated but less widely deployed Interactive Voice Response (IVR) systems that are more automated and provide many more features, often including voice recognition.

To provide additional perspective on technology implementation, also presented (see Section 2.1.1.8) are results from the Volpe Center's work on what they term a "core suite of technologies" for each type of transit agency. This work does not capture the penetration of technologies but does identify primary technologies and their application to agencies of differing sizes and types of service.

Figure 1 provides a general summary of the status of ITS technologies that were planned or expected to be in operation by 2005 at transit agencies in the United States. The information in this figure is based on the responses received from all 516 transit agencies on transit technology deployment. While it is a challenge to interpret the term "planned" in this chart, it does indicate that U.S. transit agencies definitely value technology by showing significant interest in continuing its deployment.

Please note that the status of each technology reported in the following subsections does not always include the number of agencies that have deployed the technology. The status was taken directly from the aforementioned *Advanced Public*

[8] Radin, *Advanced Public Transportation Systems Deployment in the United States.*



Note: A total of 516 transit agencies were surveyed.

Figure 2. Status of intelligent transportation system architecture development as of 2004.

Transportation Systems Deployment in the United States—Year 2004 Update, which did not always coincide with the technologies covered in *Advanced Public Transportation Systems: The State of the Art—Update 2006.*[9]

2.1.1.1 System Integration

This technology category includes elements that are required to integrate various IT and ITS elements either within an agency or among transit agencies in a region. (ITS refers broadly to a wide range of advanced technologies for surface transportation, including sensors, surveillance, communications, data processing, etc.) Both agencywide and regional integration provide an opportunity for seamless information exchange among deployed systems.

National and regional ITS architecture and standards. The U.S. DOT developed the National ITS Architecture to facilitate the integration of services between and among transportation stakeholders using standards and protocols. An ITS architecture describes processes and procedures to integrate ITS systems and subsystems at three levels: transit agency–level IT/ITS architectures, regional ITS architectures, and project-level architectures.

In an ITS architecture, the information is described at both a logical and physical level. The logical architecture defines functional processes and information flow at a high (or system) level. Information described in the logical architecture is used to define detailed information flows at the equipment (or subsystem) level—the physical architecture.

According to the FTA National ITS Architecture Policy on Transit Projects issued in January 2001, all ITS projects shall conform to the National ITS Architecture and standards. The FTA policy introduced three specific requirements for transit ITS projects that use federal funding. These are to perform a systems engineering analysis, develop a project-level ITS architecture (if a regional ITS architecture is not yet in place), and develop a regional ITS architecture.

Figure 2 illustrates the status of regional ITS architecture development across the country as of 2004. Out of the 189 transit agency respondents in the 78 largest metropolitan areas, 55 agencies reported that regional architectures were complete in their regions and 71 agencies reported that regional architecture development and planning was in progress. Among the remaining 327 agencies (those not in the 78 largest metropolitan areas), 49 reported that architectures have been developed for their region and 113 reported that architecture development was in progress. These figures show that the regions in which many transit agencies operate have been slow to develop ITS architectures.

Enterprise data management systems. A number of transit agencies in the United States are beginning to use enterprise data models to organize, maintain and use the data being generated by their ITS and IT systems. Enterprise

[9] Ibid; Hwang et al., *Advanced Public Transportation Systems.*

data consist of information from various units within a transit agency such as service planning, scheduling, operations, and maintenance. Enterprise database management systems (DBMS) provide a platform for seamless data exchange by sharing enterprise data from various departments within a transit agency. Enterprise DBMS are driven by agency policies and procedures for centralized data management and involve development of a logical data model (technical organization and structure of the database), data dictionary (definitions of data and the interrelation between various data elements), data exchange formats, and security/data access procedures and policies.

Geographic information systems (GISs). GISs facilitate the creation, management, analysis, and display of spatial transit data such as routes, stops, facilities, and points of interest. Further, GISs have a critical role in supporting ITS applications such as automatic vehicle location (AVL), automatic passenger counting (APC), and trip-planning systems with an ability to locate transit data on a map. A typical GIS includes the following components:

- A relational database management system;
- Software for creating, updating, and managing GIS data; and
- Customized GIS applications, such as asset management.

Agencies such as Tri-County Metropolitan Transportation District (TriMet), UTA, and WMATA are now managing their spatial data within enterprise DBMS to reduce operations and maintenance costs by having a centralized GIS database.

Communications systems. Voice and data communication systems serve as the foundation of many ITS applications that are used in transit planning, operations, maintenance, and incident management functions. Transit agencies need a robust communication system with interoperability across various types of communication networks for exchanging data with other regional transportation agencies and with emergency and public safety organizations.

Common communication technologies—which can be categorized as mobile, landline, and short-range wireless—include analog and digital radio, fiber optic networks, digital subscriber line (DSL), and wireless local area network (WLAN). Table 2 summarizes the deployment status of communications systems at U.S. transit agencies.

Two communications technologies of particular note are wireless fidelity (Wi-Fi) and Worldwide Interoperability for Microwave Access (WiMAX). These technologies are significant because they enable important wireless transit applications like real-time, on-board video surveillance and passenger Internet access. Although both technologies are currently in use, they are still emerging and evolving, especially WiMAX, which offers range and bandwidth advantages over Wi-Fi but is less mature. Wi-Fi and WiMAX are not technologies per se, but rather trade group certifications of technologies that utilize Institute of Electrical and Electronics Engineers (IEEE) specifications 802.11 (Wi-Fi) and 802.16 (WiMAX). Both Wi-Fi and WiMAX are in use by transit. For example, King County Metro conducted a 5-month trial of Wi-Fi on two of their bus routes, Altamont Commuter Express has offered Wi-Fi on some of their trains for several years and Caltrain (a commuter rail operator in California) recently conducted the first successful U.S. rail "proof of concept" demonstration of WiMAX, at travel speeds up to 79 miles per hour.[10] Although WiMAX has been developing and deployments have been occurring over the last couple of years in the absence of standards, a major recent breakthrough occurred in December 2005 with IEEE's official approval of the 802.16e wireless mobile area network standard. The availability of standardized, interoperable WiMAX equipment will accelerate WiMAX implementation.

2.1.1.2 Fleet Management

Fleet management technologies assist in transit planning, operation, and maintenance functions. The following sections describe specific technologies in use in the transit industry to support such functions.

Transit operations. Operational technologies provide supervisors and transit managers with the real-time status of transit vehicles that are in operation. Transit operation technologies can be categorized as follows:

- **Rail operation control system.** This includes electronic vehicle identification, communication-based train control (CBTC), video processing, center-to-center communication, supervisory control and data acquisition (SCADA), and interfaces to other systems with a need for real-time information.
- **Bus operations system.** This includes mobile data terminals (MDTs), computer-aided dispatch/automatic vehicle location (CAD/AVL) software, fixed-route scheduling and

[10] "Metro Bus Riders Test Country's First Rolling Wi-Fi Hotspot: Pilot Wireless Internet Service Begins Today on Two Cross-Town Routes," press release (Seattle, WA: King County Department of Transportation, September 7, 2005), www.metrokc.gov/kcdot/news/2005/nr050907_wifi.htm; *Business Wire* Editors and Writers, "Altamont Commuter Express and PointShot Wireless to Launch First-Ever Wi-Fi Train Access in the United States," *Business Wire* (August 25, 2003), http://findarticles.com/p/articles/mi_m0EIN/is_2003_August_25/ai_10686906; "Caltrain Succeeds with High-Speed Internet Connectivity," press release (San Carlos, CA: Caltrain, July 31, 2006), www.caltrain.com/news_2006_07_31_high-speed_internet.html.

Table 2. Status of deployment communication systems.[11]

Category		Number of Agencies in 78 Largest Metropolitan Areas	Number of Agencies in the Remainder of the United States
Technology	Trunked	50	68
	Digital only	23	43
	Trunked and digital	34	70
Planned Updates	To a digital system	19	21
	To a dedicated 800 MHz system	24	16
	To an areawide 800 MHz system	34	70
	No updates	102	233
Communication with Public Safety Agencies	Dedicated radio channels	35	69
	Joint interoperable systems	30	41
	No direct means	98	196
Interoperability with Public Safety Agencies	Communication switch	10	18
	Join interoperable system	54	61
	No plans	98	204

runcutting software, and software modules to support incident management/reporting, maintenance, and operations supervisors' functions.

- **Dynamic scheduling and paratransit operating system.** This includes MDTs, scheduling and dispatching, CAD/AVL, and incident management and reporting.

Figure 3 shows the status of AVL system deployment in the United States. Figure 4 shows the status of MDT system deployment.

Service planning support. Service planning support systems include tools and applications that facilitate managing the data that flow to and from other fleet management systems (e.g., systems assisting in transit operations). Examples of these tools include the following:

- APCs that can determine ridership by location and time of day,
- Automatic download and running time analysis using AVL data,
- Route and pattern tracing tools that assist in generating and modifying GIS inventory of routes and patterns needed by on-board ITS systems,
- Passenger-facility planning tools that facilitate managing a bus stop inventory,
- Reporting tools for decision making,
- Operator assignment management tools, and
- Electronic scheduling systems (e.g., fixed route scheduling software).

Figure 5 shows the deployment status of APC systems by mode in the United States. The deployment status of automated operations software by mode is shown in Figure 6.

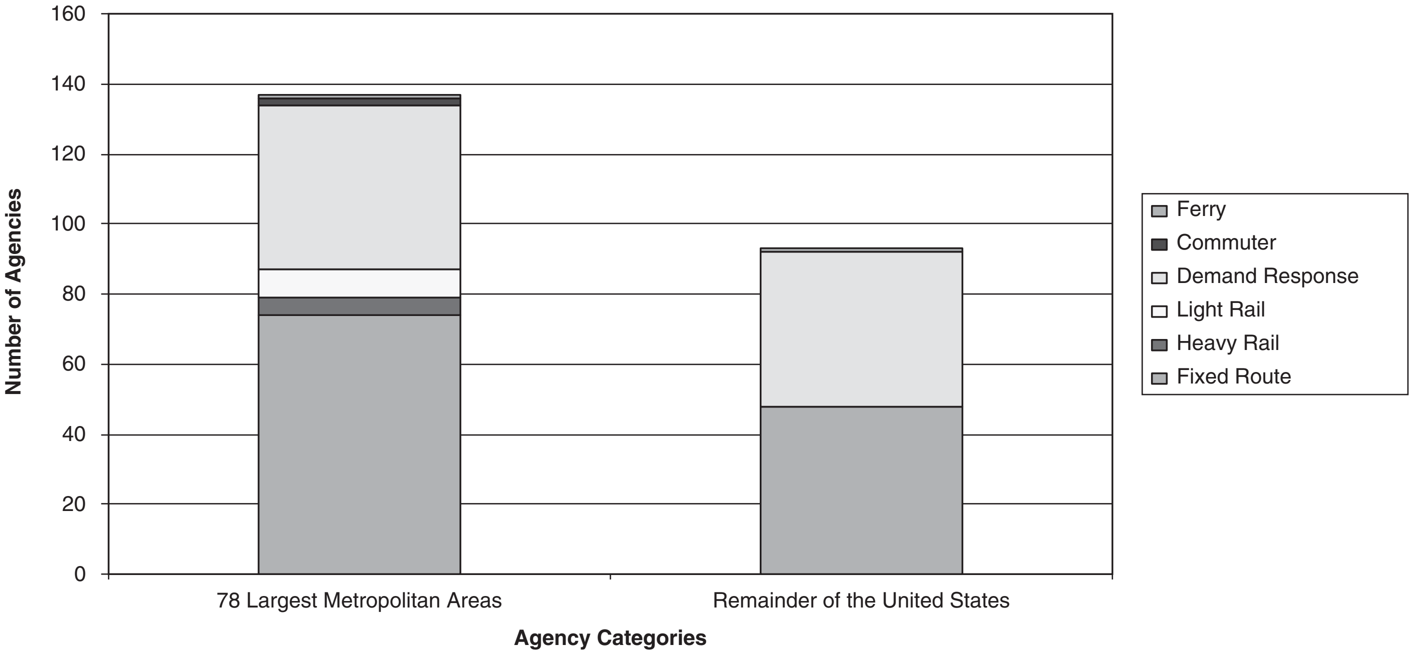
Maintenance management systems. Maintenance management systems (MMS) perform "health checks" of on-board vehicle components and report exceptions. These systems provide the real-time status of propulsion, braking, oil pressure, and other on-board vehicle functions automatically. The status is tagged with time and location information. Vehicle health and alarm information is analyzed by the MMS to identify exceptions. Then, maintenance staff is notified of the problem before the vehicle pulls into the garage. Work orders and a list of spare parts are generated automatically for corrective maintenance. A list of recurring failures can be created and provided to the management staff.

MMS technologies include fluid management systems, inventory management systems, vehicle component monitoring, maintenance records management systems, warranty monitoring and management, and electronic component tagging.

Figure 7 shows the status of deployment of vehicle component monitoring systems by mode.

Transit signal priority (TSP). TSP systems use sensors to provide priority treatment to transit vehicles approaching

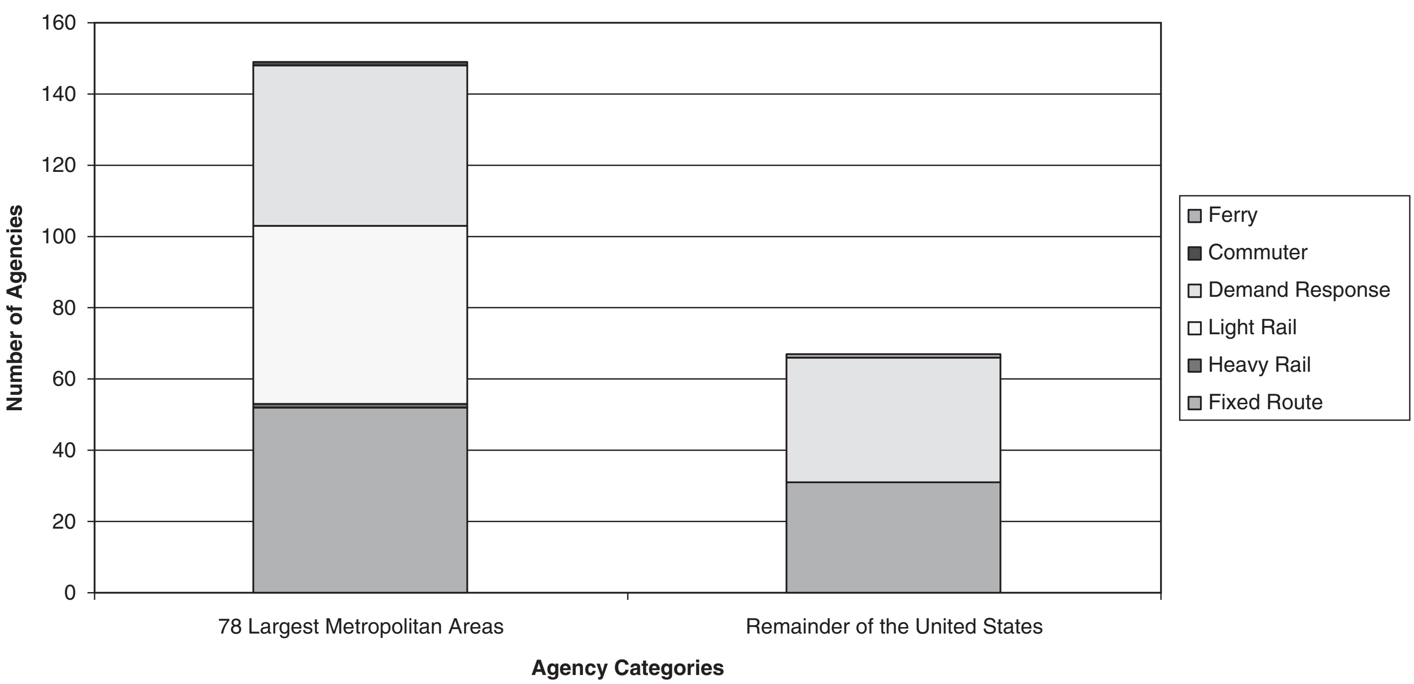
[11] Radin, *Advanced Public Transportation Systems Deployment in the United States.*



Note: A total of 516 transit agencies were surveyed.

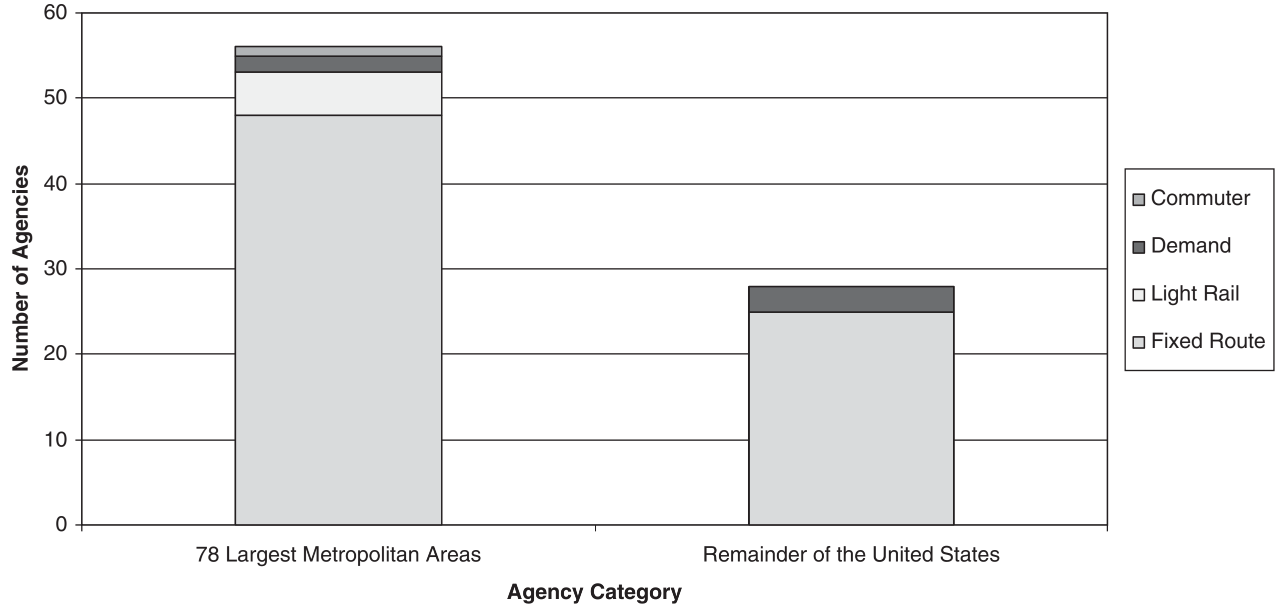
Figure 3. Deployment status of AVL systems.

an intersection. As TSP systems require modifications to traffic signal operations and do have some impacts on other traffic, TSP implementation depends upon cooperation and coordination with traffic signal operators. TSP systems technologies include vehicle-to-wayside communication technologies (e.g., optical tag readers, radio, and Wi-Fi); signal controllers; and communication systems for center-to-center and center-to-field data flows. A TSP system minimizes the amount of time spent at an intersection by transit vehicles by using strategies such as extended green phase, queue jumping, "buses-only" signals, or use of "bus-only" lanes. Priority algorithms consider various traffic and transit



Note: A total of 516 transit agencies were surveyed.

Figure 4. Deployment status of MDTs.



Note: A total of 516 transit agencies were surveyed.

Figure 5. Deployment status of APC systems.

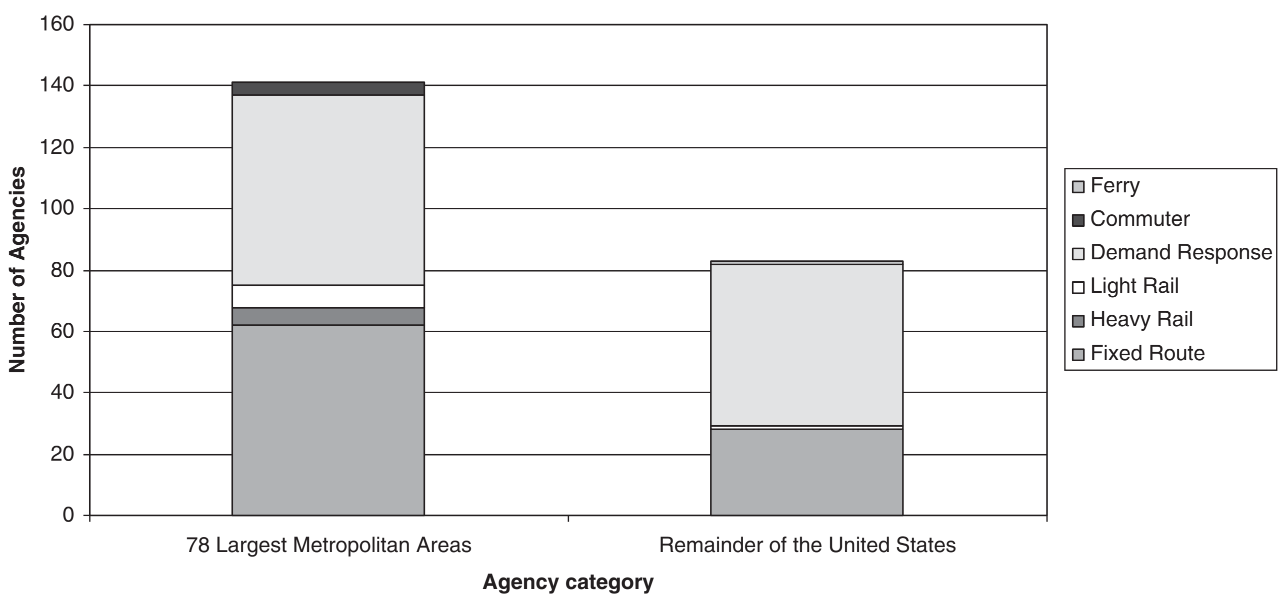
parameters (e.g., traffic volumes, queue lengths, time since last priority, headway, and schedule adherence status) before giving signal priority to transit vehicles.

Transit signal priority can be requested at both intersection ("distributed approach") and system levels ("centralized approach"). In the distributed approach, vehicles request priority at upcoming intersections. In the centralized approach, transit management centers request priority from a center that manages the signal system (e.g., a traffic management center).

2.1.1.3 Electronic Fare Payment Systems

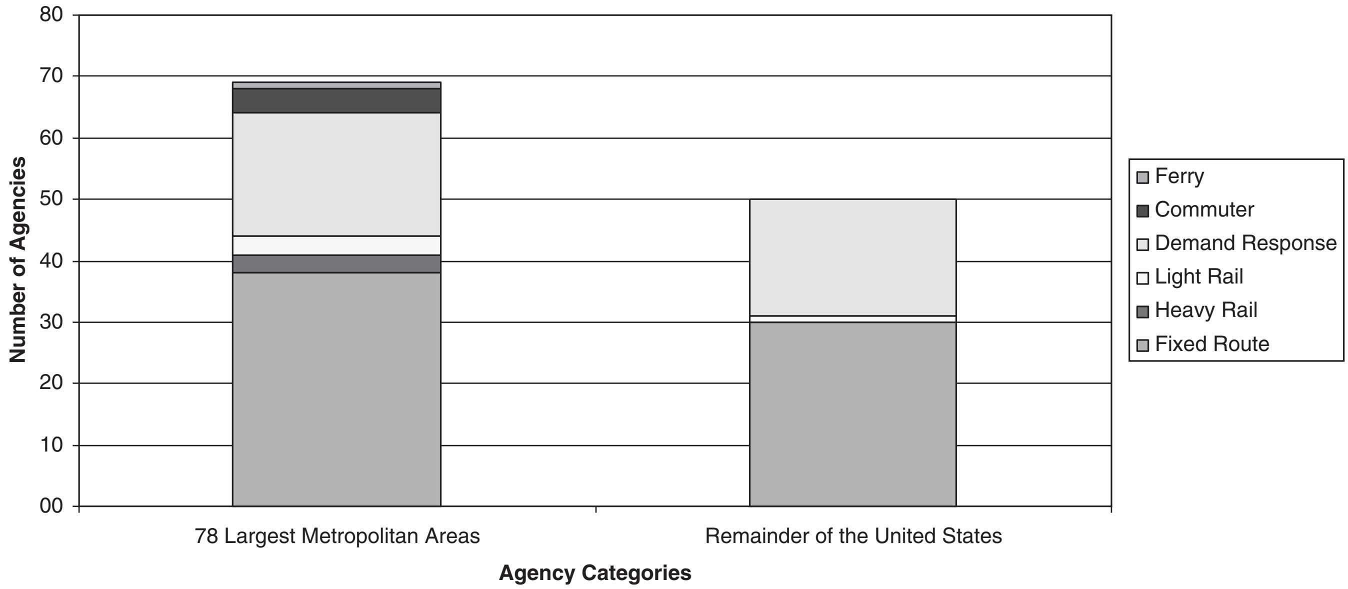
Electronic fare payment (EFP) systems provide automated vending, collection, and processing of transit fares. The following subsections describe specific components of an electronic payment system (EPS), which include fare systems, fare media, and clearinghouse (CH).

Fare systems. EFP includes hardware and software deployed by transit agencies to facilitate fare payment and collection and revenue reconciliation. EFP can be described



Notes: A total of 516 transit agencies were surveyed. The ferry level was greater than zero, but it was a low number.

Figure 6. Deployment status of automated operations software.



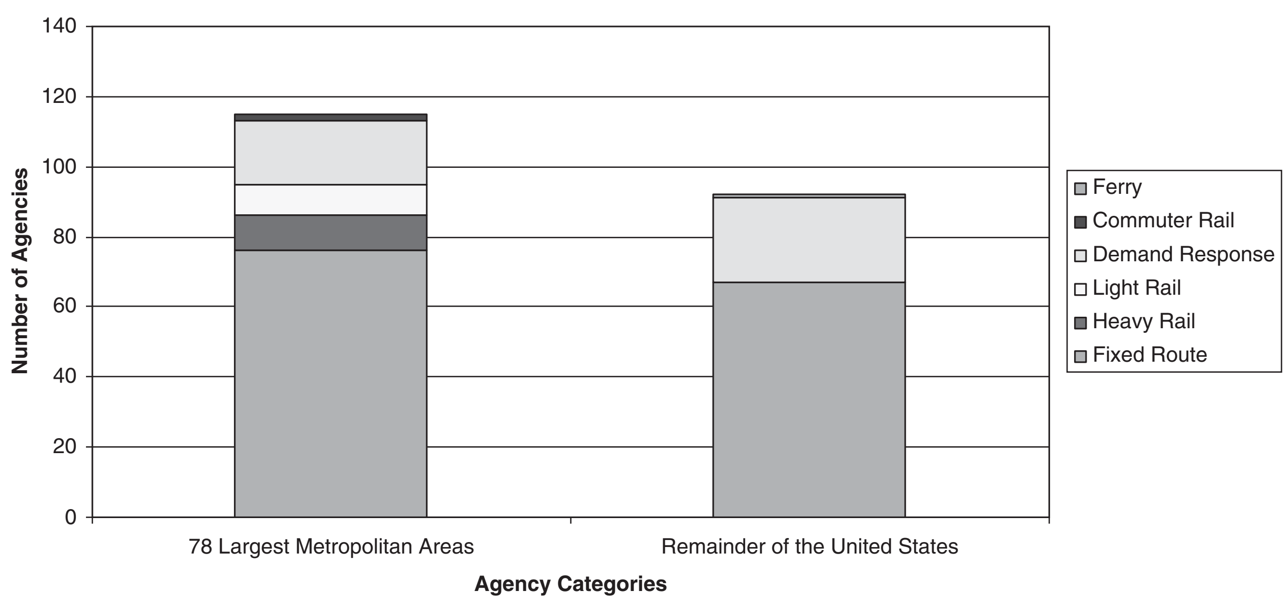
Note: A total of 516 transit agencies were surveyed.

Figure 7. Deployment status of vehicle component monitoring.

as functioning at four levels. Level 1 includes technologies that are deployed on board vehicles, in stations, and at other fare payment or sale points. These systems include card reading/writing and ticket vending. Level 2 includes IT systems at a depot level that collect data from Level 1 devices and forward the data to a central location. Level 3 includes the central IT infrastructure. Level 4 includes a CH and regional service center (RSC) that provides transaction clearance and multimodal and multiorganization fare reconciliation.

EFP systems include ticket vending machines, point-of-sale terminals, fare gates/turnstiles, card readers and validators. Additionally, there are systems that provide settlement functions for revenue reconciliation and assist in fare data analyses. Figure 8 shows the number of EPS systems deployed across the country by mode.

Fare media. EFP utilizes either a magnetic-stripe or smart card (contact or contactless). Further, credit/debit cards can be used to purchase fare media at fare vending machines.



Notes: A total of 516 transit agencies were surveyed. The ferry level was greater than zero, but it was a low number.

Figure 8. Deployment status of EFP systems.

Traditionally, EFP in the United States has used magnetic-stripe cards. Recently, smart cards have begun to be used for faster boarding and customer convenience. Contact smart cards have an embedded microchip that makes contact with an electrical connector when the card is inserted into a reader. Contactless cards have an embedded antenna, which along with an embedded microcontroller, provides "tap-and-go" functionality using radio frequency identification (RFID) technology. There are also hybrid cards (also called combi-cards) that allow one chip to be accessed by both contact and contactless readers. Also, there are cards with emerging technology that can support both magnetic-stripe and smart card functionalities.

CH. Typically, a CH assists in clearing and settling fares and generates financial and management information. RSCs assist in other activities, such as fare policy management, branding/marketing, and fare settlement and management functions.

CH/RSC systems help in establishing seamless and convenient travel across the region using a single fare product. The CH/RSC systems act as secured back office data centers and include communication networks, servers, backup storage, and software systems.

Figure 9 shows the status of operational integration of electronic payment of a transit agency with other transit agencies, of a transit agency participating in a regional toll, and of a transit agency partnering with a social service program.

2.1.1.4 Automated Traveler Information

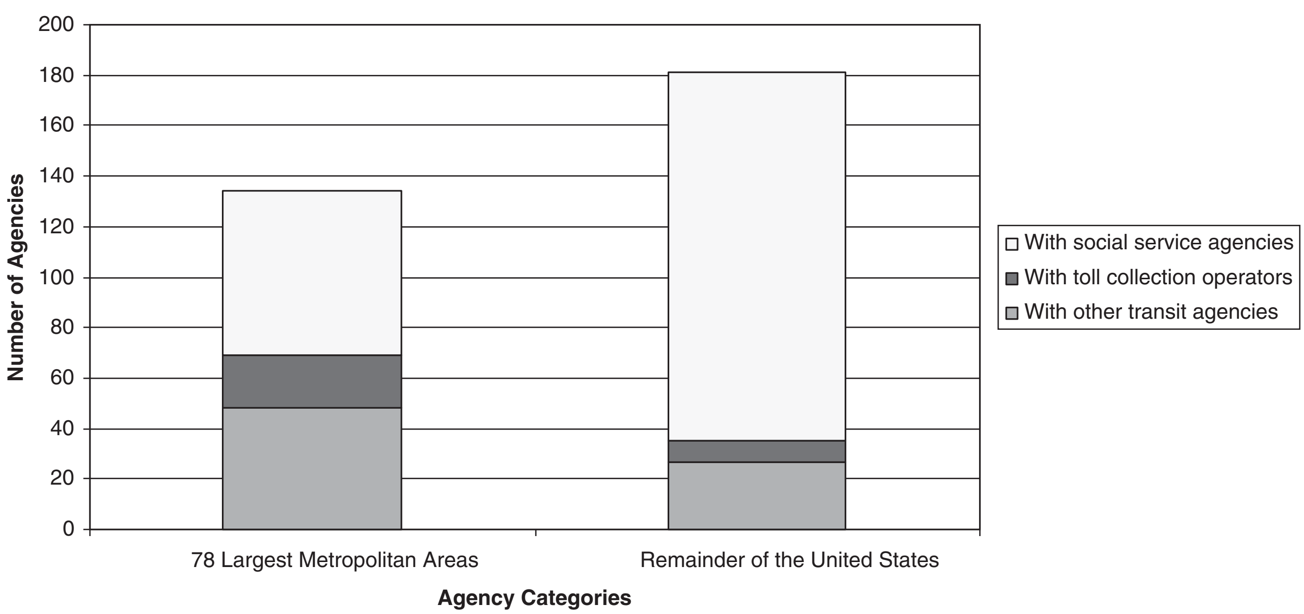
Transit agencies use various technology-based media, including websites, IVR, and television/cable networks, to disseminate automated transit information. Agencies can provide integrated traveler information using technologies such as CAD/AVL. Further, the use of these technologies can improve the accuracy and reliability of transit information (e.g., information on the arrival/departure time of the next bus).

Transit traveler information. Transit traveler information has improved a lot in recent years with the deployment of technologies such as IVR, interactive web-based mapping systems, and short message service (SMS) (text messaging) for mobile phones and personal digital assistants (PDAs). Transit agencies have taken advantage of the emergence and popularity of personal information systems such as wireless application protocol (WAP) enabled mobile phones, PDAs, MP3 players (e.g., Apple iPods), and laptop computers, to make transit information accessible. Personal information systems can provide pre-trip and enroute information.

Transit traveler information disseminated via these media is in three categories: pre-trip, wayside/in terminal, and in vehicle. The deployment status of these traveler information technologies is shown in Figure 10.

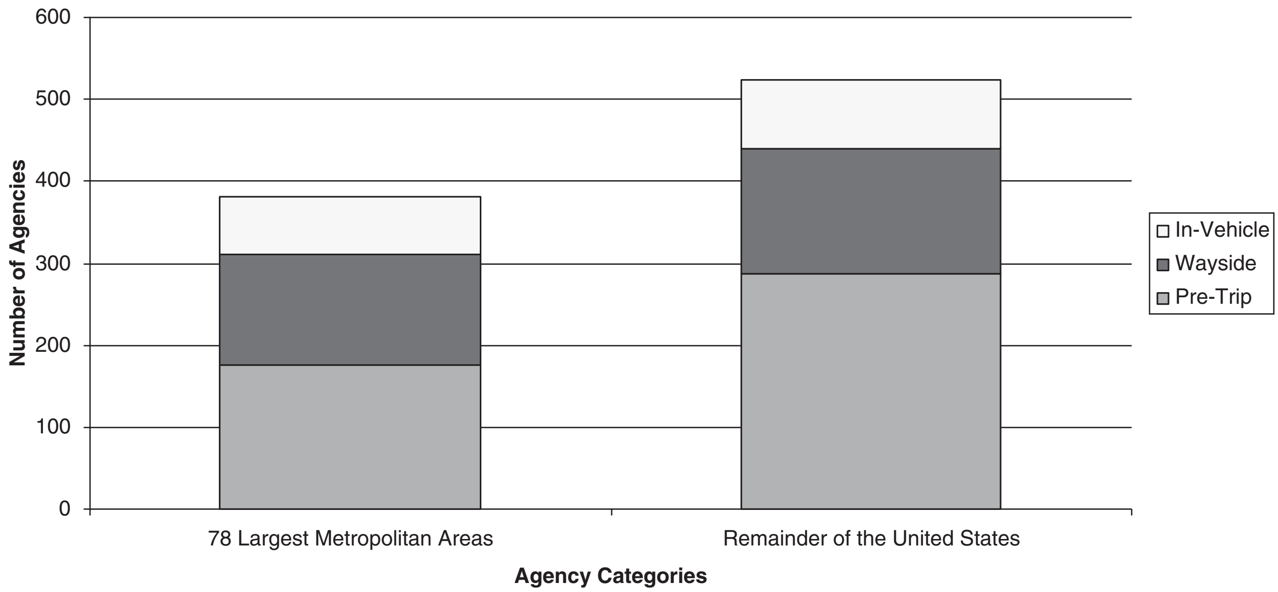
Pre-trip information. Pre-trip information can be provided to transit travelers for the purpose of trip planning. Such information can be static (e.g., bus schedules) and real time (e.g., next bus arriving in *x* minutes). Pre-trip information can be accessed via a variety of channels that include telephone, websites, IVR, and personal media (e.g., PDAs and cellular phones).

Wayside/in-terminal information. In-terminal systems provide real-time and static information on the arrival/



Note: A total of 516 transit agencies were surveyed.

Figure 9. Status of operational integration of electronic payment among multiple entities.



Note: A total of 516 transit agencies were surveyed.

Figure 10. Deployment status of various types of transit information.

departure of transit vehicles at transit stops, terminals, stations, and platforms. These systems also provide facility status information (e.g., elevator/escalator outages). Some systems also provide infrared signage (e.g., Talking Signs®) allowing vision-impaired customers to orient themselves and receive information.

Typically, in-station information is provided through dynamic message signs (DMSs)/video monitors, electronic kiosks, and platform annunciation systems.

In-vehicle information. In-vehicle information systems provide automatic visual and/or audio announcements for passengers on board transit vehicles. Typically, automatic announcements are made for the next stop, major street intersections, transfer points, and landmarks. Additionally, these systems can be used for public service announcements and advertisements. In-vehicle information can be announced both on-board and outside the vehicle.

Figure 11 shows the number of agencies in the United States in which advanced transit information systems have been deployed.

Transit traveler information infrastructure. Transit traveler information is supported by extensive data integration and management systems along with information dissemination media such as websites and PDAs. Transit databases that are to be accessed by traveler information systems need to be integrated at the transit agency level or at the regional level depending on the needs of the information system. For example, the Transport Direct system, developed by the United Kingdom (UK) Department of Transport, assists travelers in the UK with traveler information and trip planning for multiple-mode journeys (e.g., bus, train, automobile, and air) provided by multiple agencies. Transport Direct integrates separate databases—consisting of information such as flight schedules, bus and train routes/schedules, ferry routes/schedules, and street networks—that are available from several agencies. Similarly, service planning databases (e.g., routes and stops) and scheduling systems need to be integrated for itinerary planning.

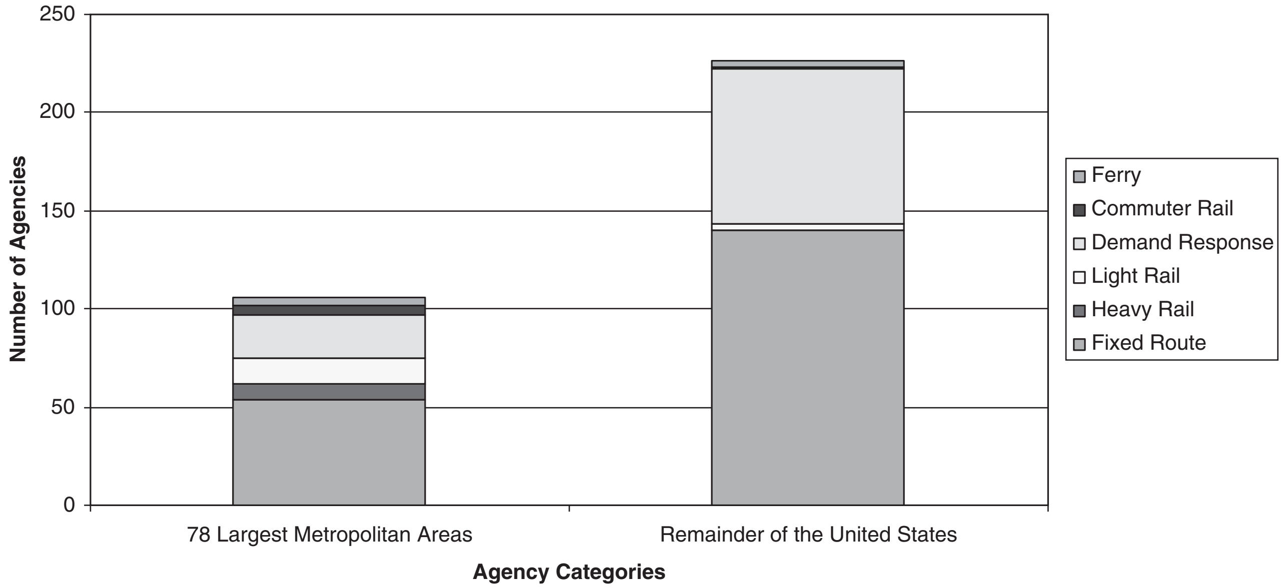
Data-driven architectures can facilitate building applications that are modular, flexible, and scalable in nature. Automated transit information systems follow "three-tiered" architectures to separate databases, business logic, and user interfaces. Transit information applications use open systems and standards such as extensible markup language (XML) and other web-based standards to ensure interoperability with other system components, especially in case of regional expansion of transit information systems.

Transit information systems can collect data from various agency partners, requiring a significant level of coordination. Another aspect of transit information infrastructure is the quality of the underlying data that are used to generate customer information, such as real-time arrival/departure information.

Figure 12 shows the number of agencies that have deployed traveler information systems across modes (e.g., rail, bus, private vehicle, and other travel modes).

2.1.1.5 Transit Safety and Security

Transit systems deploy ITS technologies to enhance security and safety in and around the transit environment. While



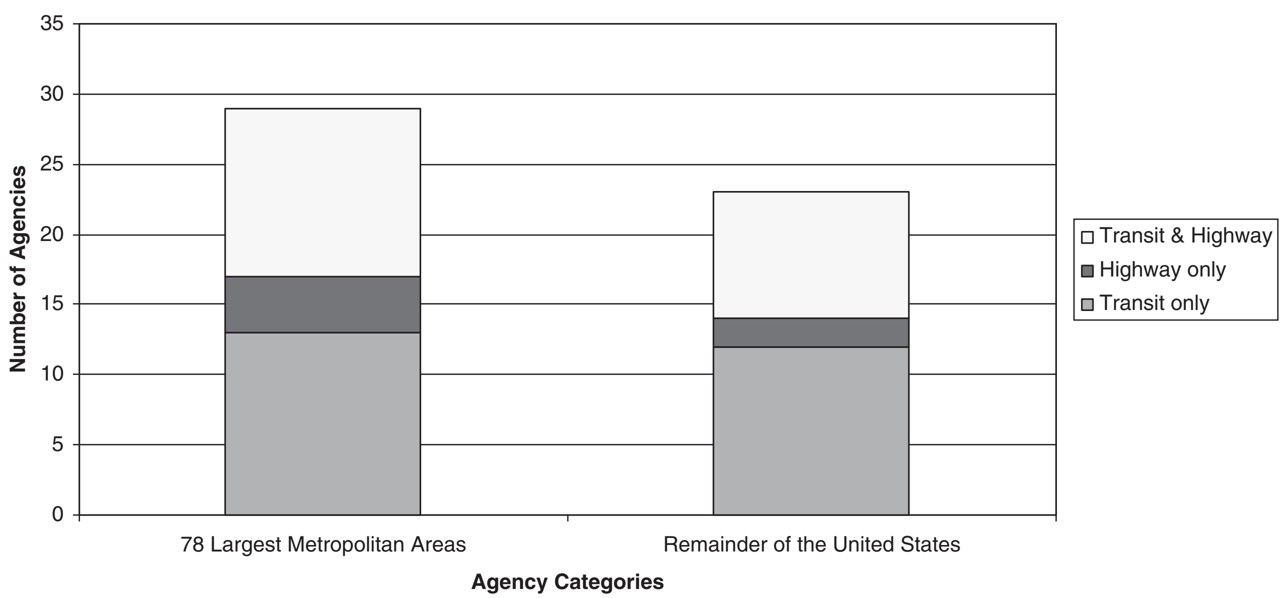
Note: A total of 516 transit agencies were surveyed.

Figure 11. Deployment status of transit information systems by transit mode.

agencies benefit from technologies such as AVL, installation of specific safety and security technologies, such as surveillance systems, increases an agency's ability to monitor and control facilities, vehicles, and other transit entities. The following types of security and safety technologies have been deployed in the United States.

On-board security. On-board safety and security systems include voice and data communication systems and video surveillance systems. Vehicle operators use mobile voice communication technologies to inform dispatchers about incidents such as security events and schedule delays.

Additionally, transit vehicles can be equipped with video cameras and analog or digital video recorders (DVRs) to capture images of on-board activities. These recorded images can be uploaded and archived to a central database once the vehicle returns to the garage. Modern surveillance systems have advanced camera features such as pan-tilt-zoom and night vision. Several transit agencies are currently experimenting with real-time streaming of on-board video.



Note: A total of 516 transit agencies were surveyed.

Figure 12. Deployment status of multimodal information.

Station/facility security. Station and facility areas can be equipped with safety and security technologies such as video surveillance; chemical, liquid, and smoke sensors; and fire alarms. Surveillance videos can be analyzed offline (after download from a hard drive) or in real time to determine the identity of a perpetrator or if legal action should be taken.

Incident response and disaster management. Incident response systems include technologies that assist in incident detection and in providing emergency response. Detection technologies assist in finding hazardous or explosive elements in a transit environment. For example, the Program for Response Options and Technology Enhancements for Chemical/Biological Terrorism (PROTECT) sponsored by the U.S. Department of Homeland Security assists in identifying a chemical release. "Puff portals" that are currently deployed at certain airports can assist in detecting explosives hidden on a passenger. Additionally, radios, alarms, and video assessment systems assist in detecting unwarranted elements.

CAD software assists in incident response in conjunction with other ITS and IT technologies such as AVL and GIS. Inside vehicles and stations, DMSs can display messages to passengers regarding the appropriate course of action to be taken during an incident. In the event of an incident, 511 systems can be used as a platform to provide assistance to travelers.

Interoperable communication systems are necessary to provide a comprehensive response to incidents. These systems provide a seamless communications network among operators, dispatchers, and supervisors. Additionally, these systems connect transit operations to law enforcement, fire, and emergency medical teams to ensure quick response in the event of an incident.

Figure 13 shows the number of agencies in the United States that have deployed incident and disaster management technologies.

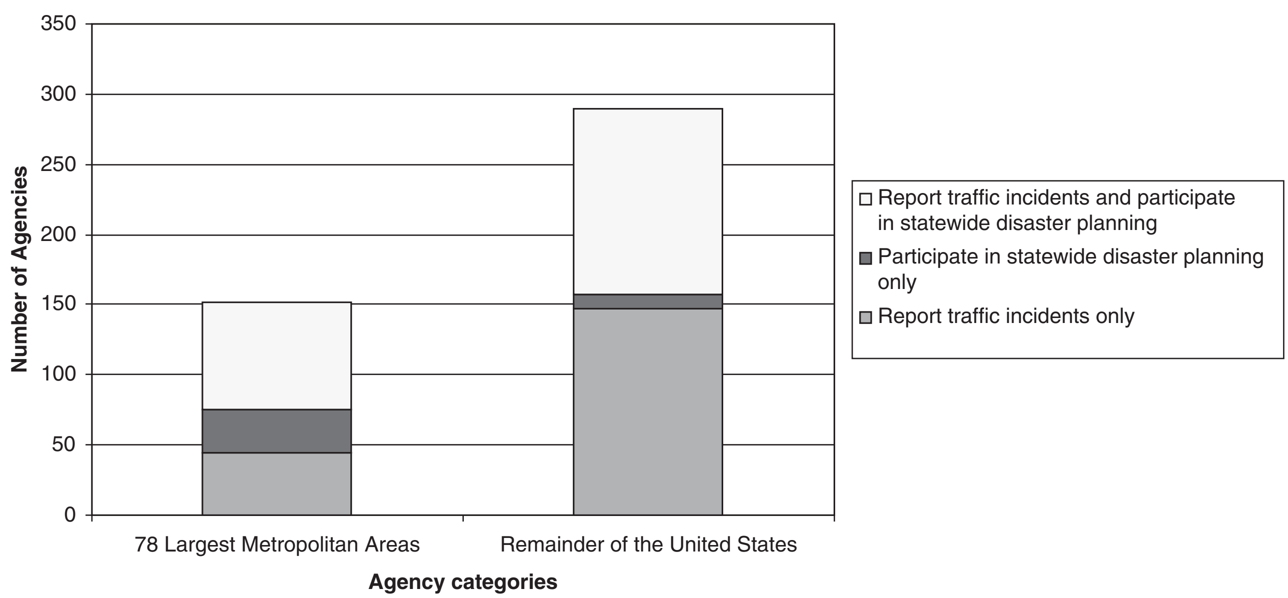
2.1.1.6 TDM

The goal of TDM (also called mobility management) strategies is to reduce the impact of traffic by changing the nature, magnitude, and distribution of travel demand. Public transit is a TDM strategy. ITS technologies that facilitate TDM can be divided into the following categories: dynamic ridesharing, automated service coordination, and multimodal transportation management centers.

Dynamic ridesharing. Dynamic ridesharing systems use technologies that assist riders in coordinating their trips with others who are taking the same trip or traveling to a nearby location. These trips can have a common origin or destination and may start at a transit stop or rideshare transfer point. Dynamic ridesharing trips use private automobiles, vanpools, and paratransit vehicles.

The ITS technologies that are used for dynamic ridesharing include automated web-based user registration and trip booking and dynamic allocation of individual trips to lowest-cost operators.

Automated service coordination. Automated service coordination uses technologies that facilitate protecting transfers (through technologies like AVL that track real-time loca-



Note: A total of 516 transit agencies were surveyed.

Figure 13. Deployment status of incident response systems.

tions of vehicles serving connections and universal fare media) for riders using multiple routes (of one agency or multiple agencies) to make their trips.

Automated service coordination systems use AVL, electronic fare collection, MDTs, decision support systems, and communication systems to identify the opportunities and need for service coordination, to monitor coordination, and to provide real-time information to passengers. Also, these systems assist in protecting connections.

Multimodal transportation management centers. Multimodal transportation management centers (TMCs) help in optimizing traffic and public transportation flow in a transportation network with the help of ITS technologies. These centers also help in emergency planning and management (e.g., TranStar in the greater Houston, Texas, region helps coordinate traffic, transit, and emergency management from one centralized location).

Multimodal transportation management utilizes ITS technologies such as wireless communications, DMSs, transit signal priority, interagency data exchange, 511, Internet, decision support systems, electronic toll collection, and machine vision. Typical functions of a multimodal TMC include the following:

- Automatic speed detection and confirmation of incidents,
- Emergency response to transportation incidents in the region served by a TMC,
- Real-time parking information for directing drivers to where spaces are available,
- Conditional priority for delayed transit vehicles, and
- Notification of adverse weather conditions.

2.1.1.7 IVS

IVS can provide advance warning of an electrical failure, management of on-board ITS systems, and adaptive vehicle control. The technologies that have been tested to date include lane keeping, vision enhancement, and driver impairment detection.

IVS technologies fall into the following three categories: on-board integration, advanced vehicle safety systems, and vehicle guidance/automation.

On-board integration. On-board integration technologies include bus- and rail-specific technologies.

Intelligent on-board bus integration technologies are meant to ensure the interoperability, usability, efficiency, and reliability of on-board systems while minimizing life-cycle costs. These technologies include digital networks, standard interface profiles (e.g., Society of Automotive Engineers (SAE) J1708/J1587 and J1939 standards), and computer software drivers for data exchange among various on-board devices.

Similarly, on-board rail integration can provide interoperability among various on-board devices. In this case, on-board integration links various subsystems across different railcars and locomotives. Rail integration uses “trainline,” a multiconductor cable that runs the entire length of the train and is supported by a high-speed digital network. The most commonly used rail integration technology is built on the IEEE 1473 standard.

Advanced vehicle safety systems. Advanced vehicle safety systems consist of warning devices installed on board to alert drivers and other operations personnel to exceptions in on-board hardware. These technologies include road departure and lane departure warning systems, rollover warning systems, collision warning systems, collision avoidance systems, and in-vehicle vision enhancement systems. Most of these systems are still under development and are expected to be deployed in the near future. These systems use a combination of sensors (e.g., in-vehicle crash sensors for collision avoidance and steering sensors for driver alert), wireless technologies, and AVL technologies based on a global positioning system (GPS).

Vehicle guidance/automation. Vehicle guidance systems reduce the workload of vehicle operators by automating various routine tasks. Such systems include navigation systems; precision docking systems that use machine vision technologies to detect painted strips; adaptive cruise control systems that assist in maintaining a safe following distance between vehicles and in coupling and decoupling (where vehicles follow one another at extremely close distances, also called close-coupled, usually in an exclusive lane); and lane-keeping assistance.

2.1.1.8 Transit Core Suite of Technologies Project[12]

There has been an ongoing need in the transit industry for basic information about technology beyond the aforementioned *Advanced Public Transportation Systems: The State of the Art—Update 2006* and *Advanced Public Transportation Systems Deployment in the United States—Year 2004 Update.*[13] In early 2006, the Volpe Center was tasked to identify a “transit core suite of technologies” and develop fact sheets for each transit technology included in the suite. The impetus for this project was to provide any agency with information that would assist its staff in determining which technologies would be

[12] C. L., Schweiger, “Cost/Benefit Analysis of Public Transport ITS in the U.S.: Successes and Continuing Challenges,” 13th World Congress on Intelligent Transport Systems (London, UK, October 9, 2006), p. 2.

[13] Hwang et al., *Advanced Public Transportation Systems;* Radin, *Advanced Public Transportation Systems Deployment in the United States.*

most beneficial for them, depending on the services they provide and their size.

The suite includes a list of the most basic and useful technologies for transit agencies based on mode and agency size. Six modes are covered, as follows:

- Fixed-route bus,
- Demand response,
- Rural transit (covers 5311-funded agencies),
- Human service transit (covers 5310-funded agencies),
- Ferry boat, and
- Rail transit.

The core suite of technologies that were defined by mode is shown in Table 3. Please note that secondary technologies are those non-core technologies that warrant consideration by agencies that have deployed the basic technologies. Some of the core technologies were considered secondary for specific modes.

As of November 2006, the Volpe Center is developing fact sheets for each of the core technologies. These fact sheets are two- to four-page summaries that describe a specific core technology, its benefits and costs, where it has been deployed, and other relevant information. The fact sheets are intended to enable an informed decision on the applicability of a particular technology to a specific public transit provider and should assist the decision maker in determining if this technology should be deployed in their agency. Further, the fact sheet should assist in determining if other technologies should be considered to gain the maximum benefit from that technology.

There are two types of fact sheets: (1) technology fact sheets that provide an overview of the technology and the application of that technology by mode and (2) modal fact sheets that provide an overview of the suite of core technologies for that mode, the technology application by mode, and core technologies by agency size. Example questions that technology fact sheets may answer are as follows:

- Why are traveler information systems good for transit?
- What should I know about maintenance tracking systems for human service transit operations?

Example questions that modal fact sheets may answer are as follows:

- Rural transit agencies can benefit from the applications of which systems?
- What should I know about maintenance tracking systems for human service transit operations?
- What technologies should I consider deploying if I run a mid-size fixed-route bus agency?

The specific contents of each fact sheet are expected to be as follows:

- Reasons to use the technology,
- Explanations of how the technology addresses transit problems,

Table 3. Core technologies by mode.

Core Technology	Fixed-Route Bus	Demand Response	Rural Transit	Human Service	Rail Transit	Ferry Boat
Automatic Vehicle Location	✓	✓	✓	✓	✓	✓
Communications	✓	✓	✓	✓	✓	✓
Traveler Information	✓	✓	✓	✓	✓	✓
Data Management – GIS	✓	✓	✓	✓	X	
Electronic Fare Payment	✓	✓	✓	X	✓	X
Computer-aided Dispatch and Scheduling	✓	✓	✓	✓		
Security Cameras/System	✓		✓		✓	X
Maintenance Tracking	✓	✓		✓	✓	
Automatic Passenger Counters	✓				X	
Traffic Signal Priority	X				✓	
Weather Information System					✓	✓

Note. X = Secondary technology for the mode.

- Common technology combinations,
- Factors to consider,
- Benefits and costs,
- Transit agency deployments and contacts, and
- Additional resources.

2.1.2 Expected and Reported Value of Technology

Three major findings related to the value of current technologies were revealed as a result of the literature review, the interviews, and the experience of the project team. As elaborated below, these findings include limited documentation of quantitative benefits, limited analysis of real "after" benefits, and, despite qualitative evidence that technologies have been useful, many deployments that have fallen far short of their full potential. These findings are described in more detail below.

There is a limited documentation of observed (as opposed to estimated), quantified benefits of technology to transit agencies. While great strides have been made in the last several years to disseminate information regarding benefits, many of the reported benefits are anecdotal in nature and are somewhat dated. This has led to a basic lack of understanding of the benefits and the lack of an adequate baseline for agencies to use in formalizing their expectation of benefits or to transfer the reported benefits to their particular operation.

Benefits information is available through channels such as the "ITS Benefits, Costs and Lessons Learned Databases" and the series of reports providing a snapshot of the information collected by the U.S. DOT ITS Joint Program Office (JPO) on the impact that ITS projects have on the operation of the surface transportation network.[14] There are also two reports available that were prepared by the Volpe Center on the benefits of technology in transit.[15] Several of the benefits reported in these documents are presented in Section 2.1.2.1.

[14] The "ITS Benefits, Costs and Lessons Learned Databases" is available on www.benefitcost.its.dot.gov/. The most recent report in the JPO ITS series is Mitretek Systems, Inc., *Intelligent Transportation Systems Benefits, Costs, and Lessons Learned: 2005 Update,* FHWA-OP-05-002, prepared for the ITS JPO (Washington, D.C.: FHWA, U.S. DOT, May 2005).

[15] D. Goeddel, *Benefits Assessment of Advanced Public Transportation Systems (APTS),* DOT-VNTSC-FTA-96-7, prepared by John A. Volpe Transportation Systems Center Research and Special Programs Administration, U.S. DOT (Washington D.C.: Office of Mobility Innovation, FTA, U.S. DOT, July 1996), www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/414.pdf; D. Goeddel, *Benefits Assessment of Advanced Public Transportation System Technologies, Update 2000,* FTA-MA-26-7007-00-4, prepared by John A. Volpe Transportation Systems Center Research and Special Programs Administration, U.S. DOT (Washington D.C.: Office of Mobility Innovation, FTA, U.S. DOT, November 2000), www.itsdocs.fhwa.dot.gov/jpodocs/EDLBrow/@101!.pdf.

The limited and often dated published information on the observed benefits of transit technologies is a significant impediment to more, and more successful, technology deployments. Such information is vital to the FTA in making funding and research decisions and to individual agencies in making investment decisions. One way to address this data shortage is for the FTA to be more aggressive in requiring agency technology grant recipients to conduct formal, quantitative, post-deployment evaluations. Mechanisms like the FHWA Joint Program Office's IPAS (ITS Program Assessment Support) Program are another method for conducting impact assessments of transit technology investments. In addition to generating much-needed data, evaluations provide transit agencies a valuable opportunity to increase the learning value of their technology deployments, including taking stock of their motivations, methods, and next steps.

There is little to no assessment of the "real" benefits *after* the technology is deployed. The small number of post-deployment ("after") analyses that are done are conducted, for the most part, by the IPAS program. Post-deployment analyses are very rarely conducted by transit authorities themselves.

It has been noted that there are many "challenges associated with obtaining accurate cost and benefit data for an 'after' analysis, including the fact that data that is needed to calculate 'after' costs and benefits may not have been collected after the deployment of the ITS. For example, if an automatic vehicle location (AVL) system has been deployed, there may be an interest in evaluating the before and after number of non-revenue miles. If this information is not routinely collected, an evaluation using this measure cannot be performed."[16]

Even though there is a lack of comprehensive, quantitative, post-deployment data, there is strong evidence that there have been many benefits to deploying technology. Further, as expected given the interviewee pool for this study (composed of successful technology adopters) there was a great deal of support for advanced technologies. Although most interviews did not focus on specific benefits of technology, interviewees demonstrated strong, implicit support for utilization of advanced technologies.

Nonetheless, the value of advanced technologies must be actively "extracted." That is, the value is only realized when technology investments are tied directly to specific agency and customer needs and applied within an explicit operational strategy. Simply "plugging in" the technologies does not generate benefits; the technologies must be applied within an explicit operational strategy.

[16] Schweiger, "Cost/Benefit Analysis," p. 2.

Although many agencies have derived some important benefits from their technology deployments, many implementations are providing far less than their full potential benefits. There are three reasons for this performance. First, the processes that have been used to deploy technology have often not effectively addressed institutional issues (i.e., no formal and robust change management processes were employed) and/or not addressed technical issues with sufficient rigor (i.e., have not utilized a systems engineering process). Second, agencies have not taken full advantage of technology. For example, while many agencies have deployed CAD/AVL systems, very few agencies have used the data generated from these systems to restructure their services. Finally, agencies have not fully integrated the technologies that they have deployed.

The sections that follow present various findings related to the value of current technologies, including those findings related to the preceding three major conclusions.

2.1.2.1 Documented Benefits of Deploying Technologies

While the benefits of technology deployment can be quantified, the benefits of many system deployments are available only in qualitative terms. This subsection discusses the documented (reported) benefits for current technologies—first, the qualitative, general reported benefits and then the specific quantitative benefits. Current technologies considered include those discussed in Section 2.1.1. Reported general benefits of these technologies, by category, are as follows:

- **System integration.** System integration, "when implemented from an enterprise-wide perspective and a regional perspective when appropriate, improves the overall usability of a technology environment made up of products from many different vendors on multiple platforms and data from many different systems. Integration is also valuable to transit ITS in that it facilitates a 'system' of interconnected ITS applications that collectively produce services and advantages far greater than the ITS applications could achieve independently."[17]
- **Fleet management.** Fleet management provides operations and planning benefits for transit organizations, and forms the backbone for many other transit technologies. AVL systems provide several operational benefits, including improved incident response time, improved schedule adherence, improved dispatcher efficiency, reduction in fleet requirements, increased transfer convenience through connection protection, reduced emissions, and reduced non-revenue vehicle miles/hours. Maintenance data obtained from the fleet management components assist in vehicle component monitoring.
- **Electronic fare payment systems.** Electronic fare payment systems facilitate revenue collection, which reduces manual processes and also provides important data for analysis of new fare policies.
- **Automated traveler information.** Automated traveler information provides travelers with information needed to make decisions regarding mode(s), route(s), and time of travel. Benefits include reduction in call volume at agency customer service centers, reduction in pollution, and increased customer satisfaction. Relevant and accurate information can help agencies win customers' confidence and achieve higher customer satisfaction.
- **Transit safety and security.** Transit safety and security assists transit agencies in providing safe and secure environments for customers and agency employees and assists with law enforcement and emergency management to monitor and manage incidents.
- **TDM.** TDM promotes and increases the use of high-occupancy vehicles, including transit, by providing multiple options for modes, routes, and times of travel.
- **IVS.** IVS can improve operational safety, reduces property losses and congestion, and reduces fuel consumption.

Reported quantitative benefits of transit technologies are summarized below.[18]

A marginal benefit analysis that was conducted by the Fort Worth Transportation Authority as part of a technology needs assessment and selection process showed a potential benefit of approximately $210,000 to $430,000 for the deployment of fleet management and traveler information systems.[19]

The GPS-based CAD/AVL system deployed at the Denver Regional Transportation District (RTD) on its 1,355-vehicle fleet included system software; dispatch center hardware; in-vehicle hardware; field communication equipment; and initial training, planning, and implementation services. This system is highly rated by RTD dispatchers. Results show that operators and dispatchers were able to communicate more quickly and efficiently with the new system. Approximately 80 percent of the dispatchers and 50 percent of the operators found the system "easy" or "very easy" to use. The system succeeded in improving bus service by decreasing the number of late arrivals by 21 percent.[20]

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[17] Hwang et al., *Advanced Public Transportation Systems,* p. 38.

[18] C. L. Schweiger and J. B. Marks, "Final Memorandum: Task-3 Conduct Cost/Benefit Analysis," Fort Worth Transportation Authority and North Central Texas Council of Government (1998); TranSystems, *Development of a Continuing Process;* ITS Cost Database (Washington, D.C.: ITS JPO, U.S. DOT, 2005), www.benefitcost.its.dot.gov/ITS/benecost.nsf/ByLInk/CostHome.

[19] Schweiger and Marks, "Final Memorandum."

[20] TranSystems, *Development of a Continuing Process.*

The Metropolitan Atlanta Rapid Transit Authority (MARTA) in Atlanta, Georgia, estimates that they save approximately $1.5 million per year through schedule adjustments using APC and AVL data. The AVL system helped Prince William County, Virginia, save approximately $869,000 annually. TriMet in Portland, Oregon, reported an annual operating cost savings of $1.9 million as a result of their CAD/AVL system implementation. An AVL system helped the London Transit Commission in London, Ontario, save $40,000 to $50,000, which would have been spent on conducting a schedule adherence survey.[21]

APC systems provide several operational benefits by providing key data for schedule adjustments. APCs also reduce manual data collection costs and improve the accuracy of ridership figures. London Transit Commission reported a savings of $50,000 on manual methods for rider counts. MARTA also reported a reduction in traffic-checking staff from 19 to 9 due to the use of APCs.[22]

Technology deployments have helped paratransit systems improve their productivity, reduce operating costs, decrease dispatcher time, and reduce the number of vehicles. The availability of paratransit software helps in dispatching vehicles according to real-time demand and increases productivity. OUTREACH, a paratransit agency in Santa Clara, California, reported an annual savings of $488,000 by installing AVL/CAD software. The Winston-Salem Transit Authority (North Carolina) reported several operational improvements after CAD/AVL deployments. Operating cost per vehicle-mile decreased by 8.5 percent to $1.93 per vehicle-mile, operating cost per passenger decreased by 2.4 percent to $5.64 per passenger trip, and operating cost per vehicle-hour decreased by 8.6 percent to $24.70 per vehicle-hour.[23]

Transit signal priority (TSP) system deployments have resulted in cost savings by reducing dwell time and unnecessary idling at signals. The Los Angeles Department of Transportation (LADOT) and Los Angeles County Metropolitan Transportation Authority (LACMTA) estimated a savings of $6.67 per vehicle-hour due to the deployment of TSP. Helsinki City Transport in Helsinki, Finland, reported a fuel savings of 3.6 percent after the deployment of a pilot TSP program on one route. King County Metro in Seattle, Washington, experienced a reduction of 57 percent in average delay at intersections. Charlotte Area Transit System (CATS) in Charlotte, North Carolina, experienced an average reduction of 4 minutes in total travel time of buses using TSP.[24]

Electronic fare payment (EFP) deployment often results in increased revenue and reduced fare handling costs. EFP also helps agencies monitor fare evasion. The Metropolitan Transportation Authority (MTA) in New York reported a 50-percent reduction in fare evasion after the implementation of the New York City Transit (NYCT) MetroCard system. MetroCard helped MTA realize additional revenues of $43 million in 1993 and $54 million in 1994. Most of the additional revenue was due to the reduction of fare evasion, but other factors included the convenience of fare payment and availability of free transfers using MetroCard.[25]

The smart card electronic payment system in Ventura, California (called GoVentura) resulted in savings of $9.5 million per year in reduced fare evasion, $5 million in reduced data collection costs, and $990,000 in transfer slip elimination.[26]

Technology deployments have helped to improve the safety and security of transit vehicles, stops, stations, personnel, and riders. Improvements in safety and security have also helped from a financial perspective through a reduction in insurance claims. For example, data from the Southeastern Pennsylvania Transportation Authority (SEPTA) in Philadelphia and other transit systems indicate a reduction of 10 to 20 percent in the total dollar amount of insurance claims due to the installation of video cameras and recorders on board transit vehicles.[27]

The examples mentioned above show reductions in the cost of transit operation due to the installation of advanced technologies. Although these examples identify significant benefits, some of the information is several years old. Information obtained from the ITS matrix is based on data from the 1990 to 2000 timeframe.[28] Information obtained from the ITS Cost-Benefit Database is somewhat more current, providing information through 2003.[29]

Examples have been cited mainly for fleet management systems, including CAD/AVL and APC systems and EFP systems. Monetary benefits related to providing ATIS have not been mentioned because such information is not documented in the national literature. However, earlier in this section, several qualitative benefits attributed to ATIS were mentioned—these benefits were reported as part of customer surveys and workshops.

2.1.2.2 Anecdotal Evidence of the Value of Technologies for Transit

Although there are limitations with the reported data on deployed technologies, it is clear that many important benefits have been realized. Even the interviewed agencies who feel that

[21] Ibid.
[22] Ibid.
[23] Ibid.
[24] Ibid.
[25] Ibid.
[26] Ibid.
[27] Ibid.
[28] The ITS Matrix was on the Mitretek website at http://web.mitretek.org/its/aptsmatrix.nsf. However, this link is no longer active.
[29] The ITS Cost-Benefits Database is no longer available on the Internet.

they have not been able to take full advantage of technologies feel that technologies have provided important benefits. As one interviewee put it, "I can't imagine trying to manage a transit agency without these technologies." Another interviewee, a representative of a large U.S. public transportation agency, who described himself as "not a 'technology guy' per se" and "not an early adopter," indicated that advanced technologies were of great value to his organization.

The technology focus of nearly all of the transit operators interviewed, especially the U.S. agencies, is on implementing, replacing, or expanding technologies that have been successfully applied in the public transportation environment for several years, including the following:

- AVL,
- Electronic payment systems (including integrated regional smart cards),
- Passenger information displays (including estimated arrival time signs, Internet trip-planning systems, kiosks, and on-board displays),
- Vehicle-component (health) monitoring,
- On-board and facilities surveillance cameras,
- TSP, and
- Management information systems (including maintenance and inventory management software).

Current technologies cited as particularly valuable by the international interviewees include automated train operation; widespread surveillance camera monitoring, in some cases coupled with automated image detection; training simulators (for drivers and dispatchers); MDTs; and smart cards.

Although the interviewees indicated that advanced technologies are very valuable, many of them strongly emphasized that the value of the technologies lies in their ability to address specific needs, that is, they are not believers in "technology for its own sake." Also, even if a technology theoretically helps address a problem, simply acquiring the technology and "plugging it in" is not effective. Rather, the organization must articulate, and then follow through on, a specific strategy for use of the technology. For example, installing AVL equipment provides little benefit if location data are not actively utilized by dispatchers in managing real-time operations and by other business units in planning and analysis.

The importance of linking technology investments with specific, identified organizational needs and strategies was emphasized by many of the interviewees. This point was made especially strongly by the UPS representative, who explained that "business driving technology decisions" and an "IT (Information Technologies) organization consistently aligned with the company's core business strategy" are cornerstones of UPS' successful approach. UPS attributes much of its success adopting technology to the transformation that has occurred in their organization over the last 15 years. A key aspect of that transformation emphasized the application of technology capabilities to specific problems—moving IT personnel from "isolated 'technical wizard' to involved 'problem-solving partner.' " Another key aspect of the UPS transformation was the move toward making technology funding decisions based on the business value they will generate. For example, "projects are prioritized based on the strength of their business cases (e.g., service to UPS customers) and financial metrics (return on investment, net present value)."

2.1.2.3 Technology Performance

As noted earlier, it is a generally accepted conclusion that U.S. transit agencies have been very challenged with regard to technologies and that many implementations have failed or under-performed relative to expectations and technical potential. The three primary reasons for this underperformance are as follows:

- Agencies have not focused on what are known to be the most critical aspects of technology deployment. Specifically, systems engineering and change management (both discussed in Section 2.2.2) have not yet been embraced throughout the industry.
- While many agencies have deployed technology, very few have taken full advantage of the technologies deployed. For example, while many agencies have deployed CAD/AVL systems, very few have used the data generated from these systems to restructure and improve their services.
- Agencies have not fully integrated the technologies that they have deployed.

The interviews yielded a great deal of information related to this last issue—the limited integration of technologies. In addition to upgrading or replacing aging current-technology systems like AVL, a number of the agencies interviewed are increasingly focusing on (1) integrating deployed systems that have been operated separately and (2) integrating data generated by technology systems like AVL more fully into their planning and analysis processes. For example, Ride-On is now working to integrate their AVL system with other on-board systems, including APCs and security cameras. As part of their AVL system replacement project, Portland's TriMet is investigating an on-board vehicle area network—an integrated computer network for on-board components—and an integrated communications infrastructure for rail and bus. WMATA is investigating integration of on-board systems and is currently implementing a regionally integrated EFP system that features a single "back office" financial processing center.

A good example of the overall trend toward increased integration and sophistication in the treatment of current technology applications is the WMATA "Customer Communications Center" project now in development. Concerned that many different entities within the organization were communicating with customers in an uncoordinated and occasionally contradictory fashion, WMATA has recognized the need to develop a dedicated center through which all of their customer communications will be channeled. Although it will probably not initially feature use of any entirely new technologies, the center represents a very important evolution in passenger information and customer communications, specifically, a recognition of the importance of these functions and the need for integration.

A common theme from the interviews was that although most agencies remain focused on current technologies, they are still "breaking new ground" in the increasingly sophisticated ways they are planning, implementing, and operating the technologies. The emphasis on maximizing the utility of existing systems is reflected in a comment by the WMATA interviewee: "We're at the stage where we're looking to get all of the data out of the systems." The increasing focus on integration and optimization of technologies on the part of the more progressive transit agencies suggests that there is a relatively long "digestion" process for advanced technologies. Although these technologies may be implemented within a few years, it takes many more years to take full advantage of them. So, rather than moving on to the next generation of technologies, many agencies are focusing to a large extent on getting the full value out of current technologies.

The international interviewees evidenced the focus on integration and application of technologies (as opposed to implementation of "new" technologies per se) even more than the U.S. agencies. For example, several of the interviewees feel that most of the basic technologies needed to support the next major advances in passenger information are in place (such as GPS-equipped cell phones and cell phone/PDA hybrids). These agencies point to interagency coordination as the greatest current challenge, especially in utilizing multiple providers to serve a single trip.

The international interviewees generally expressed less interest in discussing the value of individual technologies per se. Instead, they were more interested in talking about how the technologies could be useful within the context of overall regional mobility and asset management strategies, including those that explicitly recognize and seek to impact development patterns.

Figure 14 graphically illustrates a continuum of perspectives on advanced technologies, indicating the general differences among types of agencies apparent from the interviews.

The relative emphasis on current versus future technologies is somewhat different at commercial shippers, such as UPS, than at the U.S. and international transit agencies. The transit agencies focused almost exclusively on current transit industry–specific technologies, in particular, upgrading and integrating their existing applications and taking small, incremental steps toward technologies like Wi-Fi that are not yet common in transit, but are not truly "future" technologies. Like the transit agencies, UPS takes a very pragmatic approach to technology investment that often manifests itself as incremental additions to existing applications and approaches. However, UPS definitely devotes greater attention to anticipating and investigating future technologies than do the transit agencies. Whereas existing technologies seem to exhaust the resources that even technology-savvy, progressive public agencies can devote to technology, UPS appears able to commit

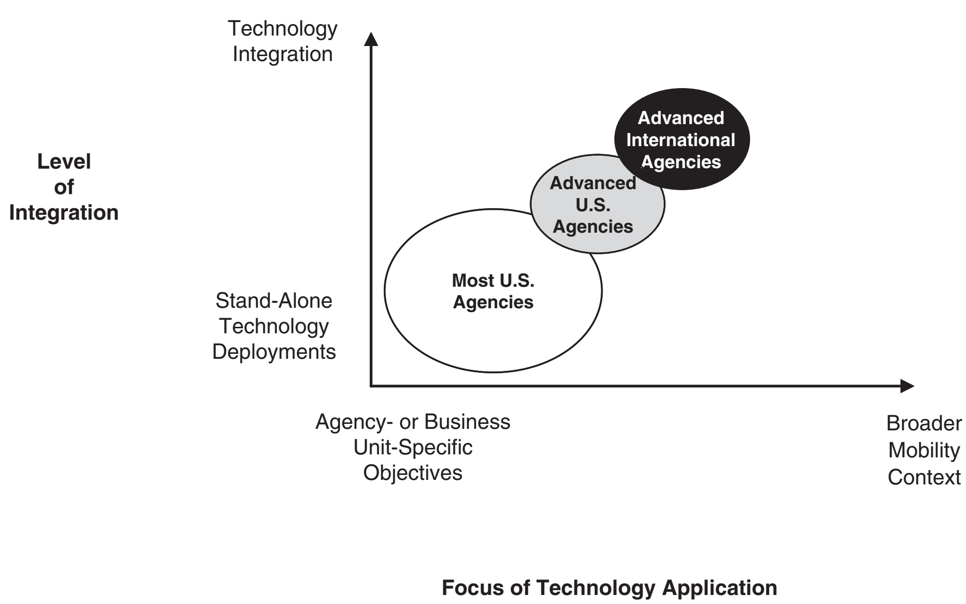

Figure 14. Evolution of approaches to advanced technologies.

resources to looking beyond current technologies. Their approaches to doing so are discussed in the next section.

2.1.2.4 Quantifying Technology Benefits Is Challenging

There are several challenges that are inherent in conducting cost/benefit and ROI analyses for public transport ITS. The challenges include the need for high-quality cost and benefit data for hardware, software, and services that have not yet been procured (by the agency conducting the analysis); the need for operations and customer service data describing the situation "before" and "after" technology is deployed; and the difficulty associated with introducing subjective factors into specific quantitative analysis methods.

If pure quantitative methods are used to perform a cost-benefit analysis (CBA), the cost and benefit data must be precise in order to minimize error. In a "before" analysis, there are challenges associated with obtaining precise cost and benefit information for the following reasons:

- Unique features of transit systems lead to variable costs and benefits for the same components/services.
- There is often a lack of detailed data available, and the available data may not be reliable or applicable.
- There can be reluctance and restrictions on the part of vendors to release cost information outside of responding to a formal invitation for bids or request for proposals (RFPs).
- The life cycle of ITS components is not well known.
- A risk assessment may not have been performed (which can be applied to costs and benefits).
- Many benefits (and some costs) may be challenging to quantify and monetize.
- Even when quantified, monetizing benefits can be challenging.

2.1.3 Examples of Successful Agency Approaches for Maximizing Technology Value

One of the objectives of this portion of the study (the value of current technology) was to describe how agencies have successfully developed business cases for technology investments. The overall finding in this area is that few agencies perform rigorous, quantitative ROI analyses. Although often successful in justifying investments, most agencies' rationales for investment rest on qualitative analyses of the need for and expected benefits of the technologies. This section describes one relatively rare example of a rigorous ROI analysis within the context of the agency's overall, state-of-the-art technology implementation approach. Two other agency examples are described that featured similar overall implementation approaches, but with less emphasis on ROI analysis.

The analysis of each of these agencies' processes yielded one major conclusion. Although not common, ROI analyses are very important, not just in supporting the right investment decision and cultivating support, but in guiding the overall implementation. An ROI analysis facilitates a "before" and "after" evaluation by establishing the "before" case and establishing the basis for judging the "after" results. A thorough ROI analysis also forces an agency to fully articulate what the specific and measurable benefits will be, which in turn encourages consideration of how the technology must be utilized to derive those benefits.

While the examples presented in the following subsections describe technology investment for three larger U.S. transit agencies, the techniques and processes these agencies used can be applied by smaller agencies. For example, no matter how large or small an agency is, their approach to deploying technology should be structured and must consider agency needs, change management, and use of metrics to identify implementation outcomes.

2.1.3.1 San Francisco Bay Area Rapid Transit District (BART)

In 2001, BART began the process of re-engineering their business into a more "mission-driven and results-oriented" environment.[30] This business advancement program (BAP) was "intended to be a fundamental rethinking and radical redesign of business core processes to bring about dramatic improvements in performance under conditions characteristic of the public sector environment."[31] At the time that BART began this project to promote a cultural change in the organization and staff, many of their systems were 20 years old. In addition, the old processes that were still being used were described as "manually intensive, time consuming, prone to data entry–errors and corrections, [not] easily allow[ing] for the automation of tasks, and provid[ing] restricted capabilities."[32]

The impetus for the BAP was not only to begin replacing old systems and processes, but also to address the organizational and process changes needed to effectively pursue technology projects. BART's IT department manager understood and educated management and staff about key issues associated with technology deployment, including why tech-

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[30] Fact sheet on Business Advancement Plan, provided by R. Cody, Department Manager, Information Technology, BART (n. d.).

[31] Ibid.

[32] IBM, "Business Advancement Plan," presentation provided by R. Cody, Department Manager, Information Technology, BART (n. d.).

nology projects fail; common pitfalls; components of successful organizational change, project management, and implementation; and risk mitigation.[33] Imparting this information to management and staff was a critical step in initiating the BAP.

The BAP process was divided into three phases: analysis, selection, and implementation. The analysis phase, conducted by an outside consultant in 2001 and 2002, consisted of four tasks: current state assessment, analysis of BAP options, investment analysis, and tactical plan development. Current state assessment consisted of conducting interviews with business, union, and information technology staff across BART, conducting surveys regarding staff perceptions of the need for and willingness to change within BART, and reviewing existing documentation. Results of this assessment determined how BART's current processes compared to industry best practices and how ready BART was to change. This assessment of business processes, cultural readiness, and information technology is a step in conducting technology projects that has been adopted by other transit agencies that have successfully deployed technology (see Section 2.1.3.3).

The assessment led into identifying BAP options, which were enterprise resource planning (ERP) for administrative functions, such as human resources, payroll, timekeeping and finance, and supply chain management for materials management and procurement.

The investment analysis consisted of developing a preliminary investment estimate, preliminary "Total Cost of Ownership" model, and preliminary CBA for the five systems that were being considered: human resources, payroll and timekeeping, integrated financial management, integrated maintenance management, and integrated procurement and inventory management. The potential benefits of the project were identified as well in order to conduct the CBA.

The cost side of the CBA used two different approaches to identifying costs: investment costs and total cost of ownership. The total cost of ownership included the same categories of costs (hardware, software, implementation, and training), and added two more: one-time internal staffing and recurring hardware and software maintenance costs. A consolidated statement was developed for costs of the technologies and for projected benefits. Both statements used a 2-year implementation period and a 5-year "steady-state" period. Then, profit statements were developed for both the investment costs and the total cost of ownership, showing by year the costs, benefits, net benefit, and cumulative benefits. Finally, for each approach, an ROI was calculated, along with the net present value (NPV) of the benefits, internal rate of return, and the number of years needed for a payback.

The first phase of the BAP concluded with the development of a going-forward plan. The second phase, software selection (also performed by a consultant) was conducted in 2003 and based on two approaches to improve administrative processes (ERP and supply chain management).[34] This phase consisted of seven tasks:

- Assemble a core team of resources for the project,
- Develop business requirements for ERP and supply chain management,
- Develop an RFP for selecting the most compatible packaged software to meet these requirements,
- Evaluate and select the software package that will best meet the requirements,
- Evaluate the future IT infrastructure requirements,
- Provide a high-level analysis of the gap between the selected packaged software and BART's requirements,
- Provide a high-level implementation strategy for the identified packaged software solution.

The final phase, implementation, began in 2004 and is scheduled to be completed in 2008. This phase is the key part of effecting the cultural change and organizational transformation. The tasks in the phase are as follows:[35]

- Design/redesign:
  - Implementation plan
  - Detailed fit/gap
  - Future process design
  - Organizational impact assessment
- Configuration:
  - Configuration baseline
  - Interface development plan
  - Test scenarios
  - Extract legacy data
  - Deployment plan
  - Acceptance yes
  - Post Go-Live support
  - Training plan
  - Organizational transition plan
  - IT test plan
- Deployment:
  - Production plan
  - Post-production implementation
  - System change management plan

[33] "Exploring Technology Implementations," presentation provided by R. Cody, Department Manager, Information Technology, BART (April 26, 2006).

[34] IBM, "Business Advancement Plan (BAP)," slides presented at project executive workshop, (San Francisco, CA: March 21, 2002).

[35] R. Cody, "Exploring Technology Implementations" (April 26, 2006).

An analysis of the process that BART is taking to ensure successful technology implementation shows that there are six critical aspects:

- Educating stakeholders about the details of the BAP project.
- Discussing the risks associated with the organizational change process and mitigating the risks by adopting specific change management and project management strategies.
- Recognizing that key knowledge, skills, and abilities (KSA) needed to effect technology deployment may not reside within the organization and should be sought by hiring an outside consultant.
- Establishing performance measures not only to quantify project success, but also to better understand the business they are in.
- Recognizing that it is changing staff behavior (not changing technology) that is probably the most important element in organizational change.
- Recognizing that successful technology deployment cannot be achieved without organizational and cultural change.

2.1.3.2 Washington Metropolitan Area Transit Authority (WMATA)

In 2000, WMATA developed a Strategic Information Technology Investment Program as part of "a necessary transformation to change the culture and bring in the reNEWed WMATA by aggressively transform[ing] WMATA from an overly hierarchical, inflexible, bureaucratic organization into an entrepreneurial, customer and business focused, empowered team." In this program, WMATA recognized that "IT is an essential ingredient of changing WMATA by providing the appropriate technology infrastructure for the new business environment. The WMATA's core business of providing transportation is increasingly driven by technology, and the ability of the WMATA to take advantage of the technological advances is a key to our long-term success."[36]

Generally, the Strategic Information Technology Investment Program established a new definition for IT, developed a technology investment process, and established clear goals and objectives for IT. An IT diagnostics review (commissioned by WMATA's GM) prompted the development of an IT strategic plan (described below). Further, WMATA reorganized the original IT group into the Office of IT and Services (ITSV), created the new position of Chief Technology Officer (CTO), and established a technology advisory committee (TAC). WMATA's Strategic Information Technology Investment Program recommends the following IT strategies: use of business process re-engineering (BPR)/business process improvement (BPI); establishment of an agency-wide technology investment process; and use of contracted services and commercial off-the-shelf (COTS) solutions. A strategic IT investment program was identified as part of the program, including the following:

- The prioritization of 55 IT projects by the TAC,
- Implementation of projects using a systems integrator concept,
- Identification of funding needs for the whole program and individual projects,
- Identification of the resource implications of the program, and
- Identified monitoring and reporting requirements.

Subsequent to the Strategic Information Technology Investment Program being announced, WMATA's Information Technology Strategic Plan was developed. The goals of the Information Technology Strategic Plan are the following:

- Establish management control over the IT resources of WMATA;
- Provide cost-effective, efficient, manageable, and maintainable support; and
- Upgrade WMATA's IT infrastructure.

The Information Technology Strategic Plan "identif[ies] the methods and resources that IT will need to employ to accomplish its goals and those of WMATA."[37] Further, the Information Technology Strategic Plan identifies 20 strategic principles that are governing the development and deployment of technology throughout WMATA. The Information Technology Strategic Plan also establishes an implementation strategy that includes specific projects, including those in the areas of technical/infrastructure, application systems, and ITS.

The technical/infrastructure projects of note include those related to enterprise architecture—specifically the enterprise hardware, enterprise management system, and enterprise-wide IT disaster/recovery program.

In November 2002, WMATA published its 10-Year Capital Improvement Plan (CIP), which includes an Infrastructure Renewal Program (IRP), covering information technology improvements in addition to several physical improvements. The CIP articulates a new vision for improving mobility in the region, which "employs technological innovation and demand management strategies to provide seamless service and travel choices."[38] The IT component of the IRP identifies

[36] WMATA General Manager and Board, "Strategic Information Technology Investment Program," WMATA's Office of Information Technology and Services (n. d.).

[37] "Washington Metropolitan Area Transit Authority Information Technology Strategic Plan," (n. d.).

[38] "Washington Metropolitan Area Transit Authority (WMATA) 10-Year Capital Improvement Plan," (November 2002).

the need for a long-term approach to address the technological needs of WMATA and to ensure that a systematic replacement of systems is achieved. Enterprise architecture development is mentioned in the CIP. ITS is specifically mentioned as part of the System Access and Capacity Program (SAP) in terms of signal priority (under the "Running-Way Corridor Improvements" section of the SAP), real-time service information, and real-time and ITS-driven kiosk information (under the Customer Facilities section of the SAP).

One of the strategic directions established in the Information Technology Strategic Plan is using technology to generate revenues. A recent and innovative initiative that directly addresses this strategy, Technology Public-Private Partnership (P3) Initiative, is in the process of developing a new integrated customer communications system as its first project. This initiative was a follow-on to an earlier initiative (Strategic Alliance and Risk Assessment) and was announced in a Request for Information dated January 31, 2006 (and revised on June 19, 2006). According to the Request for Information, "the goal of this Technology P3 Initiative is to improve customer service and system reliability by taking advantage of WMATA's marquee value and in-place technology infrastructure."[39] WMATA expects that a P3 solution would not only provide technology, but also would generate revenue and/or reduce expenses or staffing, require minimal up-front costs to WMATA, and conform to available transit and technology standards.

WMATA conducted two technology symposiums for the P3 initiative on February 16 and July 28, 2006. As of August 2006, 26 companies and teams proposed to provide WMATA with hardware and services related to the integrated customer communications system.

2.1.3.3 Capital Metropolitan Transportation Authority (Capital Metro)—Austin, Texas

At the end of 2003, Capital Metro completed their "Operations Technology Assessment," which reviewed and evaluated Capital Metro's "existing systems within the operational areas of Fixed Route Services, Maintenance, Special Transit Services, Purchased Transportation and Planning."[40] This "assessment addresses the functionality and usability of the information systems, both from the perspective of users and from what is generally experienced and expected in the transit industry."[41] The results of this assessment were summarized in six major recommendations, one of which was to conduct a detailed review of business needs and processes across the entire agency in order to determine what is needed from a technology perspective to support the needs.

As a result of this study, Capital Metro issued an RFP for ITS Consulting Services in February 2004. The scope of work in the RFP included an organized approach to accomplishing the recommended actions identified in the "Operations Technology Assessment." The overall purpose of the ITS Consulting Services effort was to assist Capital Metro in these four primary tasks:

- Conducting an assessment of Capital Metro business processes and technology systems and preparing a formal document reflecting needs, requirements, impact, and recommendations as it relates to our ITS objectives.
- Develop[ing] a Scope of Services for the acquisition and implementation of selected ITS technologies.
- Assisting in the evaluation of vendor responses from the RFP.
- [Implementing] the ITS technologies selected.[42]

Capital Metro established specific business and technical objectives for the implementation of ITS, and these were used and are still being used to govern the work accomplished by the consultant. The ITS services also had to recognize the agency's overall business goals, as well as those that were directly related to technology. Further, in the RFP, Capital Metro stated not only the consultant's responsibilities, but also those of Capital Metro staff.

Capital Metro developed a structured consultant scope of work that consisted of a "best practice" process for accomplishing the four primary tasks mentioned earlier. The first element of the scope of work was for a comprehensive assessment of needs and requirements. This effort focused on a "review of current technologies and operations in order to determine specific ITS technologies that should be implemented at Capital Metro."[43] The specific tasks with this first element included the following:

- Conducting a current business process/technology review,
- Conducting interviews and obtaining executive management input,
- Assessing current technology in the transit industry,
- Identifying and prioritizing business needs,
- Recommending specific technologies to address these needs,
- Defining functional requirements of the recommended technologies, and
- Developing an action plan and an implementation plan.

[39] "Strategic Partnerships and Initiatives: Technology," presented to the WMATA Board of Directors Planning and Development Committee by Planning & Information Technology (June 2, 2005).
[40] PB Consult Inc., Karen Antion Consulting, LLC, and RCC Consultants, Inc., "Operations Technology Assessment," prepared for Capital Metro (December 31, 2003), p 1.
[41] Ibid, p 1.
[42] Capital Metro, "Request for Proposals No. 101671, Intelligent Transportation Systems (ITS) Consulting Services" (February 10, 2004), Exhibit F, p 1.
[43] Ibid, Exhibit F, p. 3.

One unique aspect of this first element was that prior to performing these tasks, the consultant was required to develop several documents that established Capital Metro and consultant responsibilities and governed the work effort throughout the entire project. These documents were as follows:

- **A detailed work plan** that describes each milestone/deliverable (and was also used to determine payment milestones) and the roles and responsibilities of each consultant team member.
- **A detailed schedule** that reflects the detailed work plan, and identifies the estimated amount of time to be spent by internal Capital Metro and consultant staff.
- **A communications plan** that documents the methods that were used/are being used to communicate the work done on the ITS Consulting Services project to the consultant team and Capital Metro. This plan defines who needs to receive information about the ITS Consulting Services project, identifies information that needs to be disseminated, outlines how project information will be communicated, and determines when information needs to be communicated.
- **A risk management plan** that describes methods for identifying, analyzing, prioritizing, and tracking risk drivers; developing risk-mitigation plans; and planning for adequate resources to handle risk. Further, it assigns specific responsibilities for the management of risk and prescribes the documenting, monitoring, and reporting processes to be followed.
- **A quality assurance (QA) plan** that describes the strategy and methods that the consultant will employ to ensure that the ITS Consulting Services project is being managed and conducted in a sound and reasonable way. Also, the plan will ensure that the project's deliverables are of acceptable quality before they are delivered to the Capital Metro project manager. Finally, the plan:
  - Identifies the QA responsibilities of the project team;
  - Defines project reviews and audits and how they will be conducted; and
  - Lists the activities, processes, and deliverables that Capital Metro will review and audit.

The second task was for the consultant to "develop a scope of services necessary to procure the ITS components selected by Capital Metro."[44] The third task was to provide assistance during the procurement process, including developing a set of evaluation criteria upon which vendor proposals would be judged, developing an agenda and guidelines for vendor interviews, and providing a written assessment of each proposal from a technical and financial perspective. Further, the consultant played a critical role during the procurement process by answering questions during the entire procurement process, evaluating and ranking the proposers, performing a cost analysis of all proposals, and providing a physical presence on site with Capital Metro project staff, especially the Steering Committee. The first three elements of the consultant's scope were completed as of June 2006.

The fourth portion of the consultant's effort, which was ongoing as of January 2007, is implementation assistance. Given the complexity of the implementation, which is being phased by mode (bus rapid transit [BRT], paratransit, rail, and regular fixed-route bus), the implementation assistance is organized according to discrete administrative and implementation management activities. For each task and subtask in the consultant's scope of work, the consultant's and Capital Metro's responsibilities are described along with the description of the work effort.

There is a designated "Project Champion" as well as a Steering Committee for the ITS program at Capital Metro, giving the project significant visibility within the agency. Each milestone of its ITS project must be approved by the Capital Metro Project Manager and Steering Committee before payment to the consultant and vendor. Capital Metro's organized and structured approach to its ITS planning, procurement, and deployment has allowed the agency to proceed successfully with a complex technology deployment while maintaining focus on day-to-day operations and working on other very high visibility projects, such as the implementation of the "All Systems Go!" plan.[45]

2.2 Methods for Improving the Success of Technology Implementations

This section summarizes obstacles faced by public transportation agencies in implementing advanced technologies and identifies a number of general strategies and specific best practices that agencies can employ to overcome many of those obstacles. The choice of obstacles and recommendations to discuss here is based on several telephone interviews and a focus group with technology managers and GMs from public transportation agencies of varying sizes; a review of literature; and the experiences of the project team in work with agencies on technology projects around the United States.

[44] Ibid, Exhibit F, p. 4.

[45] According to the Capital Metro website (http://allsystemsgo.capmetro.org/all-systems-go.shtml), "the plan addresses the pressures of regional population growth in the Greater Austin area, estimated to double in the next 25 years. Thousands of citizens have helped create the plan, which includes Capital MetroRail, Capital MetroRapid, expanded Local and Express bus services, more Park & Ride locations and possible future rail services in Central Texas."

Recommendations for overcoming obstacles and maximizing the benefits of technologies are divided into two general categories. The first category of recommendations covers the overarching strategies of enterprise architecture planning, systems engineering, and change management. The second category of recommendations identifies specific best practices in a number of areas, ranging from institutional to technical.

2.2.1 Obstacles to Successful Technology Implementation

Part of the impetus for this study is the reality that transit agencies have struggled to take full advantage of technologies, even mature technologies. One aim of the research was to improve understanding of the obstacles to taking full advantage of technology and to concisely summarize them. This summary then serves as a context for the real focus of this research, which is the identification of proven, successful practices for overcoming those obstacles.

This summary of obstacles is organized into two major sections. The first presents major findings and the second describes specific obstacles.

2.2.1.1 Major Findings Related to Obstacles

Even "successful" agencies face serious obstacles. The interviews focused on agencies considered to be particularly successful in adopting advanced technologies. Yet, even these agencies reported facing many challenges and obstacles, not all of which they feel they have completely overcome. This is evidence of the serious challenge presented by technology-related obstacles.

The international agencies and UPS also acknowledged technology-related obstacles, but they did not emphasize them as strongly as the U.S. agencies. This suggests that the international agencies and the commercial shipper are farther along in addressing those challenges. Such a conclusion would be consistent with the beliefs of many in the transit industry who feel that U.S. transit lags behind the private sector and European agencies in the area of technology utilization. The generally greater support for transit in Europe and the fact that technology is a prime means for UPS to establish competitive advantage are likely explanations for such a gap.

U.S. agencies lack the resources to systematically track emerging technology. Most agencies expend their available technology resources on current technologies and do not have resources to devote to anticipating emerging technologies. To the extent that agencies do investigate emerging technology, it's usually not a sanctioned, supported, and structured "agency" activity. Rather, the investigation, consisting of reading technology publications and networking with colleagues at other agencies, is often done "off-the-clock" by individual employees who are personally interested in technology.

Most serious obstacles are primarily non-technical. The most commonly cited and most challenging obstacles are related to various "people issues," rather than technology per se. These people issues include organizational culture, leadership, "turfism" among departments within agencies, and community attitudes about transit.

Many obstacles are deep-seated. Many obstacles to technology exploitation are deeply rooted in the overall paradigm for public transportation in the United States. The TCRP "New Paradigms" research identified a number of problems associated with traditional approaches to providing transit services, including these ones related to technology implementation:[46]

- Fragmented responsibilities, conflicting policies and goals, and separate or discrete funding mechanisms across and within transportation agencies.
- Organizational culture and dynamics posing barriers to change and deep-seated, change-resistant perspectives and attitudes on the part of many industry managers and many in the labor force.
- The failure of the quality of the customer experience to fully emerge as the dominant focus of most agencies and the continued emphasis of operational, output-based performance measures.
- A history of slow adoption of advanced technologies, or stated conversely, the absence of any widespread precedent or expectation for technology innovation throughout the industry.

The obstacles are widely understood. Failure to recognize obstacles is certainly not a prime factor in preventing transit agencies from taking greater advantage of technology. Acute awareness of obstacles and the ability to articulate their nature and impact was uniform among the agencies interviewed. There was also a high degree of correlation between the obstacles identified in the interviews and those that have been well documented. That documentation includes the literature and agency forums like the May 3, 2005, summit of public transportation agency GMs sponsored by APTA and ITS America (a summary of the summit is included in Appendix B).

2.2.1.2 Specific Obstacles

Many of the obstacles identified in the literature were also discussed by interviewees. However, presenting summaries

[46] Stanley et al., *TCRP Report 97;* Cambridge Systematics Inc., *TCRP Report 53.*

from each source ensures a comprehensive listing and provides insights into what agencies perceive to be the most serious obstacles (the ones they mention in the interview).

Table 4 summarizes obstacles from the literature organized into three major categories: institutional obstacles, technical obstacles, and financial obstacles. Many of the items in Table 4 were compiled from Mitretek as part of their work with the National ITS Cost-Benefit Database.

Obstacles cited by U.S. interviewees are summarized below.

- **Inadequate funding.** A shortage of funding for all aspects of technology-related implementation and operation, including planning and especially operations and maintenance. The King County Metro interviewee noted that technologies are of tremendous benefit but can become a "burden," e.g., resources and effort must be continually expended to develop and update policies and procedures, to maintain the systems, and so forth. The OUTREACH (Santa Clara County, California, paratransit provider) interviewee cited software maintenance agreements as a particular cost concern. One interviewee noted that most agency board members view technology as "nice, but not necessary."

A number of the agencies interviewed had few comments related to the long-term (10- to 20-year) outlook for technologies. In large part, this reflects—even among these agencies that recognize the value of technology—a shortage of resources. As one interviewee put it "We'd love to think 20 years out, but we're not there yet; our focus is on today and the next couple of years."

- **Shortage of expert personnel.** A shortage of expert personnel can lead to an over-reliance on consultants, which creates additional problems. The OUTREACH representative emphasized how continuing to rely heavily on the same limited number of consultants tends to produce the same, traditional solutions. One U.S. interviewee noted that planning and implementation/operation of technology projects is sometimes split between two different groups within transit agencies. As a result, there can be a tendency to "chase" technology funding without clear operational objectives and, once secured, "dump" the project on technology staff. Those personnel may not have the same vision for the project and may lack the capabilities or resources to maintain it.
- **"Turfism."** Internally, among agency business units, and externally, among agencies, turfism inhibits coordination

Table 4. Obstacles identified in the literature.

Category	Obstacle
Institutional Obstacles	• Issues in the mapping of agency goals and objectives with their ITS business needs; • Problems in coordinating with private agencies providing infrastructure; • Issues in interagency coordination for ITS data sharing and management; • Inability of in-house technical staff to handle data storage management and analysis; • Issues in finalizing installation locations for physical infrastructure such as ticket vending machines and dynamic message signs (DMSs); • Issues in the functional distribution of work in integrated/coordinated services, e.g., farecard distribution and revenue settlement in universal fare systems; • Issues in providing regionally coordinated services such as intermodal traveler information; • Lack of appropriate staff skills and training; • Poorly specified roles and responsibilities related to the project(s); • Lack of management support for technology innovation; and • Aversion to risk taking.
Technical Obstacles	• Issues with the accuracy and reliability of currently used GPS-based navigation systems; • Issues with the accuracy and sensor durability in APC systems; • Problems in using non-relational or proprietary databases, which are expensive and difficult to interface with; • Problems in interfacing new deployments to legacy systems; • Issues in obtaining all desired functionalities in the software purchased from vendors; • Accuracy issues associated with the traffic control systems in providing priority to transit vehicles; and • Issues with ITS data processing, storage, and management.
Financial Obstacles	• Ongoing cost of private communication networks, for example, AT&T–Cellular Digital Packet Data (CDPD) network cost problems faced by TriMet in Portland, OR; • Cost of deployment and O&M associated with on-board and wayside equipment (e.g., AVL, APC, MDT, and DMS); • Software purchase and maintenance cost; • Reliability issues in hardware and software purchased from external vendors; • Problems with allocation of costs (funding distribution) for projects with regional importance; and • Issues in the fund allocation to ITS projects in case of limited budget.

and contributes to stove-piped applications, redundancy/inconsistency, and inefficiency. The OUTREACH representative cited "tremendous bureaucracy" as a major threat to innovative technology projects, especially those projects involving multiple agencies, noting that "money flows through so many layers" and is often not available to those with good ideas for how to use it. The Ride-On representative noted that IT and ITS have traditionally been different groups within many organizations and that cooperation has not always been as good as it could be. The UPS representative noted that the organizational changes they have made over the last 5 to 10 years to better align technology investments with business decisions and to develop cross-functional teams to guide technology projects have greatly improved coordination. However, they also noted that "turfism" was a major challenge and to some extent continues to be one.

- **Long project timelines.** Long project timelines delay benefits and further hasten the already short life spans of many technologies. As the King County Metro interviewee noted, technology is constantly changing and is therefore a "moving target," and long project timelines compound the challenge. The OUTREACH representative stated that "by the time a project is fully up and running, it's all obsolete and needs to be upgraded." The interviewee from the Central Ohio Transit Authority (COTA) in Columbus, Ohio, summarized the situation as "chasing your tail."
- **A shortage of leaders.** There are not enough "champions" and "visionaries," especially among senior management and agency boards. The King County Metro representative stated that "individuals make the difference, not the process for technology development and implementation." He noted that his predecessor "personally invested a lot of time and energy; he had a vision with technology as a major focus; he created 'fertile soil' for innovative thinking—'just add water.' " The COTA interviewee noted that "it's all about the leader." The OUTREACH interviewee underscored the importance of visionary leadership: "You have to have someone who is entrepreneurial; motivated; someone willing to do the 'full court press' to build support and funding; . . . somebody has to be thinking about it (use of technologies) all the time; have an innate interest." One interviewee's comments suggest that the advantages inherent in having pro-technology leadership may in fact represent a "fragile" security. He noted that agency leadership comes and goes, and the loss of a pro-technology leader can seriously impact an agency's technology program. This suggests that it can be difficult to fully "institutionalize" support for technology, that is, to generate a supportive structure not dependent on any given leader or champion.
- **Less than fully supportive agency culture/climate.** Agency culture can be risk averse and non-entrepreneurial. The King County Metro interviewee noted the importance of "organizational self-image," an image of the agency as willing to take some risks and dedicated to improvement and utilizing the best available technology. One U.S. agency interviewee stated that "if you can't get your board and the staff to come along, you're dead."
- **Less than fully supportive community.** Lack of community support for transit overall, especially for the expenditure of transit resources on technology, can be an issue. Several interviewees, including King County Metro, Portland TriMet, and OUTREACH indicated that the overall support for public transportation and general support for advanced technologies in their regions contribute to their success. They, and other agencies, such as the Cape Cod Regional Transit Authority, also point to the presence of information technology-oriented businesses and universities, with whom they partner, as an important factor.
- **FTA policy on National ITS Architecture.** Difficulties in understanding how to comply with, and carry out compliance with, the FTA National ITS Architecture policy on transit projects. One interviewee also expressed concern that, especially in the past, FTA funded a lot of technology projects that were not well thought out by the local implementers, that did not include a concept of operations, and for which project life cycle costs had not been considered. This interviewee thought that there had not been enough "enforcement" of the FTA architecture policy and that many agencies' architecture efforts have merely been a "check off," not a meaningful exercise. According to this interviewee, "people (agencies) have figured it out and they're thinking 'why should I develop an architecture and use a systems engineering process?' or more importantly, why they should do it in a resource-intensive, meaningful manner rather than simply go through the motions necessary to demonstrate compliance?"
- **Complex, resource-intensive procurement processes.** Procurement of transit technologies is a major challenge for agencies. The procurement processes are long, demand considerable attention and expertise, and have major repercussions for the ultimate success of the deployments. One of the factors that makes procurement challenging is that many agencies expect to find COTS products that meet *all* of their needs and preferences, including the ones unique to their agency. Given the relatively small public transportation market and the pervasiveness of agency-specific requirements, very seldom are completely off-the-shelf products available.
- **Small vendor markets.** These limit competition, perpetuate proprietary and "custom" applications, and suppress innovation and movement toward standardization and interoperability. The OUTREACH representative in particular

expressed concern that the small market for transit-specific (especially paratransit-specific) technology means that nothing is truly off-the-shelf; everything has to be customized and due to the idiosyncratic, proprietary software, agencies must continue to pay vendors to update and customize technologies. In the words of a WMATA interviewee, technologies for public transportation have not become "commercialized," they are not yet "commodities." The interviewee from Ride-On noted that vendors seem intent on selling new products rather than on providing replacement parts over the long term. He stated that since there is no backward compatibility (stemming from a lack of standards), new components cannot be plugged into older systems, meaning that the entire system must be replaced.

2.2.2 Overarching Best Practices for Overcoming Obstacles and Maximizing Benefits

2.2.2.1 Embracing Enterprise Architecture Planning and Systems Engineering

This section discusses one of the major conclusions reached over the course of this study, drawing upon all of the research performed and supported by the cumulative experience of the project team in working with transit agencies to plan and implement technologies. That finding is that *if transit agencies are to improve their success with technologies, they must meaningfully embrace and effectively practice more rigorous, structured, and thorough planning and implementation techniques.*

Two such techniques—which themselves encompass a wide range of specific practices—are enterprise architecture planning (EAP) and systems engineering (SE). These techniques have been proven over time in other organizations and businesses—including the military, banking, and freight logistics—as providing tremendous benefits in improving technology deployment success. This conclusion is also supported by U.S. DOT's recognition of the need for SE for ITS and, in 2001, their requirement for SE. Finally, the small but growing number of positive experiences with these techniques in the U.S. transit industry is also evidence of their beneficial effect.

Despite the 2001 U.S. DOT requirement for SE, some transit agencies do not fully understand the technique and have not meaningfully embraced and practiced it. The purpose of this discussion is to underscore the importance of these techniques, provide some perspective on how they have been viewed by many transit agencies, and identify some possible strategies for stimulating their utilization.

What are EAP and SE? EAP is a state-of-the art strategic planning process that is specifically intended to maximize the benefits and cost-effectiveness of technology investment.[47] EAP is a more overarching strategy than SE because EAP focuses on the entire organization and establishing the context and strategy necessary to support specific technology deployments (SE is a technique typically applied to an individual technology implementation). EAP is the starting point for a strong technology deployment process and should precede SE sequentially. EAP clearly identifies the organization's business mission, goals, objectives, and strategic plans and describes the physical and logical architectures for the technologies that directly support the mission, goals, and so forth. By establishing the basis for technology investments in relation to the organization's overall mission and direction, EAP provides the necessary foundation for subsequent technology deployment activities.

SE is a structured, disciplined approach to designing and implementing complex systems. The concept has been around for over 50 years and has its roots in the development of large, complex systems for the Department of Defense.[48] SE has since become commonplace for technology systems in business. The fundamentals of SE consist of a structured, sequential, multi-step process. Key steps in that process include the following:

- Development of user needs reflecting all stakeholders who will use or be impacted by the system;
- Development of detailed and comprehensive system requirements to address all of the needs;
- Development of a concept of operations;
- Development of a system architecture;
- Rigorous verification, validation, and testing throughout implementation in which system performance is evaluated against (traced back to) the original user needs and requirements.

Scalability is a key benefit of both the EAP and SE techniques. For large, complex systems and organizations, EAP and SE processes can be very large, very resource-intensive undertakings. However, the logic, basic approaches, and benefits of both techniques are not altered or diminished when scaled down, and for small, simple projects or organizations, utilizing these techniques does not require tremendous resources.

Recognition of the value of EAP and SE for transportation. Although EAP and SE techniques are not yet widely or sufficiently understood or practiced by many public transportation agencies, they are beginning to penetrate the over-

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[47] Hwang et al., *Advanced Public Transportation Systems.*

[48] Mitretek Systems, Inc., *Building Quality Intelligent Transportation Systems Through Systems Engineering,* FHWA-OP-02-046, prepared for the ITS JPO (Washington, D.C.: U.S. DOT, April 2002).

all transportation environment. One example of increasing awareness is the inclusion of EAP in *Advanced Public Transportation Systems: The State of the Art—Update 2006.* In that document, EAP is identified as having important benefits and is described as a method deployed by "agencies with state-of-the-art strategic planning processes." Generally, the benefits of EAP are to "improve the success and cost-effectiveness of IT and ITS investments." Specifically, "when EAP is made part of the agency's strategic planning and management processes, it establishes an agency-wide roadmap to help the agency achieve its mission by supporting optimal performance of its core business processes within an efficient information technology environment."[49]

Broader recognition of the value of EAP is reflected in the federal government's many EAP-related activities. These activities include development of a Federal Enterprise Architecture Framework in 1999 and, commencing in 2002, the subsequent efforts to develop the Federal Enterprise Architecture.[50]

There are a number of examples that point toward the increasing awareness and promotion of SE for transportation. A very recent example is the January 2007 publication of *Systems Engineering for Intelligent Transportation Systems—An Introduction for Transportation Professionals,* sponsored jointly by FHWA and FTA.[51] The report does not specifically comment on, or link its purpose and objectives to, the historically slow penetration of SE into transportation. However, the report's very existence and targeting of a "traditional" transportation planning and engineering audience (as opposed to systems engineers, per se) seem to respond to that reality.

Another example, and one that explicitly acknowledges the slow penetration of SE into transportation, is the joint development of the 2005 "Systems Engineering Guidebook for ITS" by the California Department of Transportation (Caltrans) and the Federal Highway Administration California Division.[52] The same sorts of conclusions about public sector transportation agencies' difficulties in taking advantage of technologies that have motivated this study are also cited in the report's foreword:

> Intelligent Transportation Systems (ITS) is now over 15 years old as a program of operational initiatives. Over this time, Intelligent Transportation Systems have gradually evolved, becoming more complex and integrated. It seems, though, that we are still in the infant stages of ITS developments. We have not seen the full benefit of how technology can make our transportation facilities more efficient. In many cases, we are still struggling with mainstreaming ITS into the traditional transportation planning and project development process. Several ITS programs have started with the best of intentions but have failed to produce their envisioned goals.

The report goes on to identify the lack of consistent, structured project development processes as a key reason for failed or underperforming ITS investments and recommends SE. The report identifies the following benefits of increased utilization of SE by transportation agencies:

- Improve the quality of ITS;
- Reduce the risk of cost and schedule overruns;
- Gain participation of multiple agencies and a diverse set of stakeholders;
- Maintain, operate, and evolve the ITS;
- Maintain consistency with the regional and state ITS architectures;
- Provide flexibility in procurement options for the agencies; and
- Keep current with rapid evolution in technology and needs of transportation.

The Florida Department of Transportation (FDOT)'s vigorous support of SE is another example of the concept's validation and penetration into the transportation environment. FDOT has recently developed guidance for "Developing a Project Systems Engineering Management Plan."[53] FDOT identifies systems engineering as a necessary and useful tool to manage the increasing complexity and risk of ITS deployments. FDOT requires SE not only for FHWA-funded projects (per FHWA Rule 940), but for all projects on the Florida Intrastate Highway System, regardless of funding source. FDOT states that utilizing SE "maximizes the quality of the system being implemented while minimizing the budget and time required for its completion."[54]

Although not necessarily widely and vigorously practiced by all public transportation agencies, SE and its value have been recognized in the transit literature. For example, *Advanced Public Transportation Systems: The State of the Art—Update 2006* states, "the systems engineering component to FTA's Policy on the National ITS Architecture is extremely important when developing ITS projects. In fact, it becomes an essential component at all stages of the project's life cycle."[55]

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[49] Hwang et al., *Advanced Public Transportation Systems.*

[50] The Chief Information Officers Council, "Federal Enterprise Architecture Framework, Version 1.1" (September 1999), www.cio.gov/documents/fedarch1.pdf. For one example of these efforts, see www.whitehouse.gov/omb/egov/a-1-fea.html.

[51] National ITS Architecture Team, *System Engineering for Intelligent Transportation Systems—An Introduction for Transportation Professionals,* FHWA-HOP-07-069 (Washington, D.C.: FHWA, FTA, U.S. DOT, January 2007).

[52] California Department of Transportation, Division of Research & Innovation "Systems Engineering Guidebook for ITS," Version 1.1 (February 14, 2005).

[53] A. Sanyal, "New Guidance for Developing a Project Systems Engineering Management Plan," *SunGuide Disseminator* (Tallahassee, FL: Florida Department of Transportation, Traffic Engineering and Operations Office, September 2006), www.floridaits.com/Newsletters/2006/09-2006/09-2006.htm#PSEMP.

[54] Ibid.

[55] Hwang et al., *Advanced Public Transportation Systems.*

Historical experience with EAP and SE in transit. SE and the basic philosophy of EAP were implicit in the U.S. DOT's approach to advanced technologies such as ITS from the beginning. The development of the first National ITS Architecture in the early 1990s itself represents an SE exercise, and the architecture's basic structure, organized around user services (derived from user needs) and requirements, reflects a central SE concept. Likewise, U.S. DOT's "IVHS Planning and Project Development Process, Version 1.0" a guidance document from 1993 (which even predates the term "ITS"—IVHS stands for intelligent vehicle highway system) and all subsequent ITS strategic planning guidance documents emphasize the link between an organization's mission and business goals and objectives and its technology investment decisions.[56]

Although EAP and SE concepts were implicit from the beginning in the U.S. DOT ITS program, they were not obvious or required and were not recognized by many practitioners. Nearly all transportation agency personnel—most of whom had no SE experience—found system architecture alien. Few of them recognized these techniques for what they would come to be—nothing less than a revolution, a paradigm shift in how transportation agencies must approach technology investment, both to comply with federal requirements and to improve their success with technologies.

As the National ITS Architecture evolved over more than a decade, it increasingly incorporated and emphasized EAP and SE concepts, such as the inclusion of a "concept of operations" for regional architectures. However, even as EAP and SE principles and techniques penetrated deeper into U.S. DOT's ITS program, there was still no explicit, formal, "introduction" of EAP and SE strategies to transportation organizations or mandates for their use. This changed, or the mandate part of it at least, in April 2001 with issuance of the Final Rule on ITS Architecture and Standards Conformity (Rule 940) and FTA's Final Policy on Architecture and Standards Conformity.[57] Although SE was still not unveiled as a technique or philosophy in any comprehensive way, both FHWA's Rule and FTA's Policy did specifically identify and require use of a seven-step "systems engineering approach" to designing federally funded ITS projects. FHWA's Rule and FTA's Policy did not, however, establish any similar requirement for EAP.

Compliance with FTA's Policy relied on agency self-certification, and there was no dedicated mechanism by which agencies' use of the SE process would be checked. Rather, understanding and compliance with the requirements were promoted through the following:

- A series of guidance documents, such as the 2002 U.S. DOT report, "Building Quality Intelligent Transportation Systems Through Systems Engineering" and the 2003 "National ITS Architecture Consistency Policy for Transit Projects—Additional Grantee Guidance."[58]
- Courses offered by the National Transit Institute (NTI).
- The FTA Architecture Oversight Assistance and Technical Assistance Program, which provided FTA-funded consultant support to agencies.

Despite the availability of these resources, by 2002 most transit agencies still did not fully understand, or buy into, SE. This conclusion is based on the extensive ITS project work that the consultant research team has performed with transit agencies around the country, their experience in providing FTA architecture oversight and technical assistance, and their experience delivering NTI courses on the FTA National Intelligent Transportation Systems (ITS) Architecture Policy on Transit Projects and systems engineering. Most agencies—and nearly all of the smaller agencies—continued to approach complex technology projects in the same way that they approached traditional equipment procurement projects. Not unexpectedly, many transit technology investments continued to either fail outright or fail to live up to their full potential.

Awareness and application of EAP as a formal strategy in transit has arguably been even slower than SE, as EAP has lacked the visibility provided to SE by virtue of its inclusion in the FHWA Rule and the FTA Policy.

Current transit use of EAP and SE. Today, several years after the 2001 FTA Policy and 2 years past the 4-year deadline for compliance with the FTA Policy, some agencies have begun to "find their way" to SE and EAP. It is unclear how much of a factor these agencies' own prior experiences and realization of the need for a more rigorous approach was in their discovery of SE and how much of a factor the FTA Policy was.

BART's BAP project is a prime example of an agency and project that is rigorously applying SE and incorporating EAP principles. Appendix A, which summarizes a focus group conducted for this study, contains a summary presentation by BART describing their approach.

The BART experience with SE as well as change management (another critical strategy, discussed in Section 2.2.2.2) represents a relatively rare, fully realized, "textbook" exam-

[56] FHWA, "IVHS Planning and Project Deployment Process," Version 1.0, working paper (Washington, D.C.: FHWA, U.S. DOT, 1993).

[57] For information on and electronic versions of the Final Rule on ITS Architecture and Standards Conformity (Rule 940) and FTA's Final Policy on Architecture and Standards Conformity, see "FHWA Rule/FTA Policy," www.ops.fhwa.dot.gov/its_arch_imp/policy.htm.

[58] Mitretek Systems, *Building Quality Intelligent Transportation Systems;* FTA, "National ITS Architecture Consistency Policy for Transit Projects—Additional Grantee Guidance," policy guidance document (Washington, D.C.: FTA, U.S. DOT, 2003), www.fta.dot.gov/documents/dc2003.pdf.

ple of SE in transit technology implementation. BART's SE approach to their BAP project is unusual and fully realized in several respects. First, the Program Director, Beth Tripp, along with her Deputy Program Director and BART Chief Information Officer (CIO), Robin Cody, combine a thorough understanding of SE with a conviction that SE, EAP, and change management practices are essential and will pay for themselves. This level of SE know-how and conviction is in stark contrast to those agencies that view SE as something they have to do to satisfy FTA (agencies sometimes feel this way because they lack understanding and experience in this area). These same agencies often turn SE wholly over to the consultants and vendors supplying their products (which defeats many SE purposes). The issue of conviction is underscored by Ms. Tripp's and Mr. Cody's decision at the beginning of the BAP process to allocate a significant portion of the funding that had been identified for hardware instead to early SE planning and conceptual design activities. The BART BAP application of SE and EAP methods is also exemplary in that all of the core SE techniques and overarching principles thoroughly permeate and are integral to the project.

Core SE activities and methods utilized in the BAP project include the following:

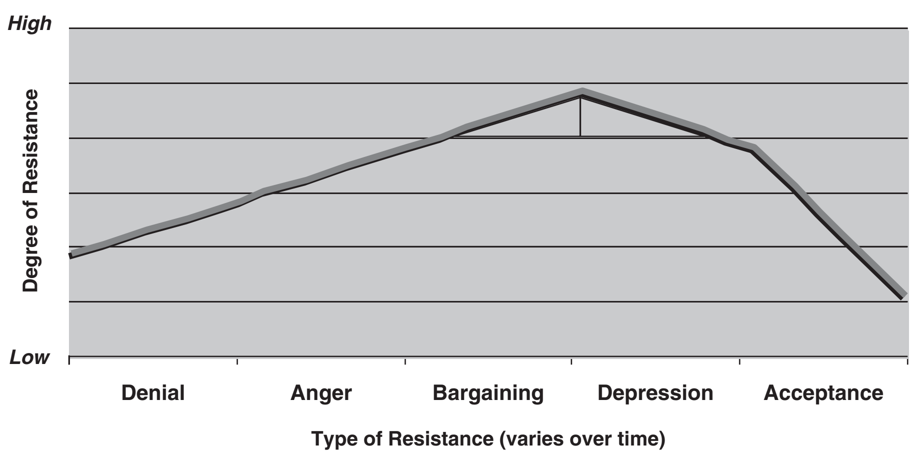
- Starting with a thorough examination of current conditions and major options (what BART calls their "Business Analysis" phase).
- Involvement of a very large and inclusive group of stakeholders throughout the project (in all three phases) including Business Analysis (300 employees participated in a readiness survey); Software Selection (200 employees participated in requirements definition and 80 employees assisted the Source Selection Committee by participating in software demonstrations); and Design-Configure-Deploy (10 employees helped develop the problem statement and 30 employees as well as union leadership assisted the Source Selection Committee).
- Development of comprehensive individual system requirements (2,600 of them) to guide the entire process from design through final validation and beyond.
- Development and implementation of thorough, structured testing and validation plans, comparing ("tracing") the deployed system to the requirements.

How to improve utilization of EAP and SE. Unfortunately, BART and agencies like them that are vigorously and effectively applying EAP principles and SE are the exception. The vast majority of transit agencies have not yet recognized the benefits of EAP and SE and/or they do not have the skills and resources to either carry these processes out themselves, or contract them out. This discussion, and the specific best practices that incorporate EAP and SE principles, are but one step in addressing these problems. Additional efforts are necessary.

The first step is to recognize three key facts:

- EAP and SE constitute a major departure from traditional transit approaches;
- There is a steep acceptance and learning curve for these techniques; and
- These techniques demand capabilities and resources that many agencies, especially small ones, do not have.

Figure 15 shows five stages of cultural resistance to change, ranging from initial denial to ultimate acceptance that apply to individual transit agencies and the public transportation industry overall in their response to the need for EAP and SE. The experience of the project team suggests that many agencies are still in the early stages of the process. These agen-



Source: Robin Cody, Bay Area Rapid Transit, 2006.

Figure 15. Stages of transit industry and agency resistance to rigorous application of EAP and SE.

cies are either unaware of, or not accepting, the need for EAP and SE and the significant changes necessary to effectively practice those techniques.

Until agency leaders buy into EAP and SE and allocate resources for them, the best practices presented here—although certainly the "keys to success" from a technical perspective—will not be enough to solve transit's technology challenges. Key steps for promoting greater, truly meaningful understanding of EAP and SE include the following:

- Effective dissemination of this report's finding that EAP and SE are essential to improving the ROI for transit technology.
- Continuation of NTI training courses on these topics and development of new courses.
- Continuation of FTA's architecture and technical assistance programs providing expert, hands-on assistance to agencies.
- Support of efforts to promote an FTA initiative, including development of white papers and presentations, creating a transit EAP template and conducting an EAP demonstration at a transit agency.[59]
- Increasing FTA regional offices' efforts to identify agencies requiring training or other assistance.
- Increasing FTA consideration of agencies' EAP and SE capabilities and commitment to the techniques when evaluating those agencies' technology *deployment* grant applications. When capabilities and commitment are inadequate, focus funding assistance to those agencies on understanding and learning how to apply these techniques (see also the discussion of prerequisites in Section 2.3).

2.2.2.2 Embracing Organizational Change Management

Like SE and EAP, change management strategies are implicit in a number of the recommended best practices presented in Section 2.2. However, like EAP and SE, the crucial importance of change management warrants its own discussion. For the purposes of this discussion, "organizational change management" refers to processes for managing the changes required on the part of the organization and individual stakeholders for successful technology strategic planning and, especially, successful implementation of technology systems.

The fact that many IT projects fail or underperform is common knowledge in the IT industry. The industry is full of literature with titles like "Why IT Projects Fail." Some of the most oft-quoted statistics documenting IT project success and failure come from The Standish Group International's ongoing "CHAOS" research, which, since 1994, has featured biennial surveys of thousands of IT projects. Although the success rate for projects has increased significantly since the first study in 1994, in the 2003 study, only about one-third (34 percent) of the 13,522 IT projects studied were fully successful (defined as on time, on budget, and with all features and functions originally specified).[60] Fifteen percent of projects failed (canceled before completion or never implemented), and the remaining 51 percent of projects were "challenged," defined as completed projects that were operational but which were over budget, late, and with fewer features and functions than initially specified. Reported failure rates for ERP projects are even higher, at 60 percent.[61]

Comparable statistics are not available for the success and failure rates of public transportation IT projects. However, most people in the industry would agree that many transit technology projects have failed or have not fulfilled their potential.

The reason *why* IT projects fail has also been the subject of much attention within the IT industry, among management consulting firms, and within the public transportation community. Within the IT industry, the perception that most failures happen because of "people" or "institutional" problems, rather than "technical" or "technology" problems is the norm. For example:

> Are most project failures caused by technical problems, people problems, or business problems? People problems. Business and technical problems boil down to people problems. The myth of IT is that it's about computers and technology. It's not—IT is about people.[62]
>
> The most common causes for IT failures are related to project management.[63]
>
> I've never seen a project fail for technical reasons. Never. Management may have picked the wrong technology for the purpose, but the technology itself wasn't the cause.[64]
>
> Why ERP Implementations Fail: 42 Percent Leadership; 27 Percent Organizational and Cultural Change Issues; 23 Percent People Issues; and 8 Percent Technical or Other Issues.[65]

[59] M. Hwang, E. Lerner-Lam, and Palisades Consulting Group, Inc., "Enterprise Architecture Planning for Transit: Bridging the ITS Deployment Gap," PowerPoint presentation to the FTA, (May 31, 2005).

[60] "Latest Standish Group CHAOS Report Shows Project Success Rates Have Improved by 50%," *Business Wire* (March 25, 2003), http://findarticles.com/p/articles/mi_m0EIN/is_2003_March%2025/ai_99169967; The Standish Group International, Inc., *Extreme CHAOS* (2001), http://www.vertexlogic.com/processOnline/processData/documents/pdf/extreme_chaos.pdf.

[61] The Rockford Consulting Group, "The 12 Cardinal Sins of ERP Implementation," white paper (November 30, 2006), http://rockfordconsulting.com/12sinart.htm.

[62] M. Betts, "Why IT Projects Fail," *ComputerWorld* (August 2005), www.computerworld.com/managementtopics/management/project/story/0,10801,84266,00.html.

[63] T., Al Neimat, "Why IT Projects Fail," white paper (October 24, 2005), http://www.projectperfect.com.au/downloads/Info/info_it_projects_fail.pdf.

[64] G. Tillman and J. Weinburger, "Technology Never Fails, But Projects Can," *Baseline* (January 2004), www.findarticles.com/p/articles/mi_zdbln/is_200401/ai_ziff116888.

[65] P. Waters, "ERP Change Management—Getting from Here to There," PowerPoint presentation at 2006 Oracle OpenWorld conference (October 22–26, 2006), http://dti.delaware.gov/majorproj/ppts/OracleOpenWorld_CMweb2006.ppt#340,1,ERP Change Management—Getting from Here to There.

In identifying the recipe for project success, The Standish Group also puts people issues at the top of the list, with "Executive Support" and "User Involvement" in the number one and number two positions.[66] "Lack of Top Management Commitment," "Resistance to Change/Lack of Buy-in," and "Poor Communications" have been identified as among the "12 Cardinal Sins of ERP Implementation."[67]

As with EAP and SE, there are proven techniques available for surmounting the human and institutional challenges of technology projects. Many of these methods fall into the category of organizational change management and are widely documented in the generally available literature on organizational change (see, for example, *Organization Change: Theory and Practice*).[68] Typical summations of organizational change objectives include the following:

- Provide awareness;
- Ensure understanding;
- Facilitate acceptance;
- Care, listen, and respond;
- Manage people's expectations;
- Ensure readiness; and
- Champion the project.

Success factors for change management include the following: [69]

- Active and visible sponsorship,
- Use of organizational change management processes and tools,
- Effective communications,
- Employment involvement, and
- Effective project leadership and planning.

As with EAP and SE, few public transportation agencies have either fully bought in to the need for change management and/or they lack the leadership or resources to practice it effectively. A rare exception is BART, which, in addition to embracing EAP and SE techniques, placed a tremendous emphasis on change management in their ongoing BAP. BART's "4 Keys to Success" for change management are typical of those identified by other types of organizations:[70]

1. Get Help!
   - Identified Business Requirements
   - Software Negotiations
   - RFP Creation
   - System Integration Negotiations
   - Project Management/Oversight
   - Provide Contemporary Technology Knowledge
2. Bring In Your Stakeholders
   - Inclusion Brings Buy-In
   - Provides Needed Expertise
   - Middle Management/Unions
3. Make This A "People" Project
   - Not A Technology Issue
   - People and Cultural Problem
   - Organizational Readiness
4. Get Unions Involved!

Figure 16, from a BART presentation on its BAP, emphasizes a comprehensive approach to change management.[71] The figure contrasts successful change management featuring the full complement of required components (vision, skills, incentives, etc.) with various failures that can be expected when some components are absent.

One of the unique and effective activities within BART's overall change management strategy was its approach to anticipating and contending with labor union concerns. Anticipating that some concerns could end up in arbitration, BART took the rather extraordinary step of previewing key elements of its project's impact on labor with an arbitrator and incorporating the feedback in its approach.

A number of the recommended best practices presented in Section 2.2 incorporate change management strategies. However, as with EAP and SE, identifying these strategies is just one step. Efforts are also needed to address the fundamental issues that prevent many agencies from utilizing change management techniques. These issues include lack of agency leadership support and lack of knowledge and skills on the part of staff for performing or effectively overseeing contractor performance of change management. The techniques recommended at the end of Section 2.2.2.1 to address concerns with SE and EAP also apply here.

2.2.3 Specific Best Practices for Overcoming Obstacles and Maximizing Benefits

This section presents specific best practices for improving technology use. First, "10 Key Considerations for Technology Implementation" are presented (Section 2.2.3.1). These are followed by best practices organized into various categories, such as "Institutional Practices" and "Financial Practices" (Sections 2.2.3.2 through 2.2.3.7).

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[66] The Standish Group International, Inc., *Extreme CHAOS.*

[67] The Rockford Consulting Group, "The 12 Cardinal Sins of ERP Implementation."

[68] W. W. Burke, *Organization Change: Theory and Practice* (Thousand Oaks, CA: Sage Publications, 2002).

[69] Waters, "ERP Change Management—Getting from Here to There."

[70] R. Cody, "The Changing Role of a CIO and BARTS' Business Advancement Program," presented to the National Defense University Information Resources Management College, (March 20, 2006).

[71] Cody, "The Changing Role of a CIO and BARTS' Business Advancement Program."

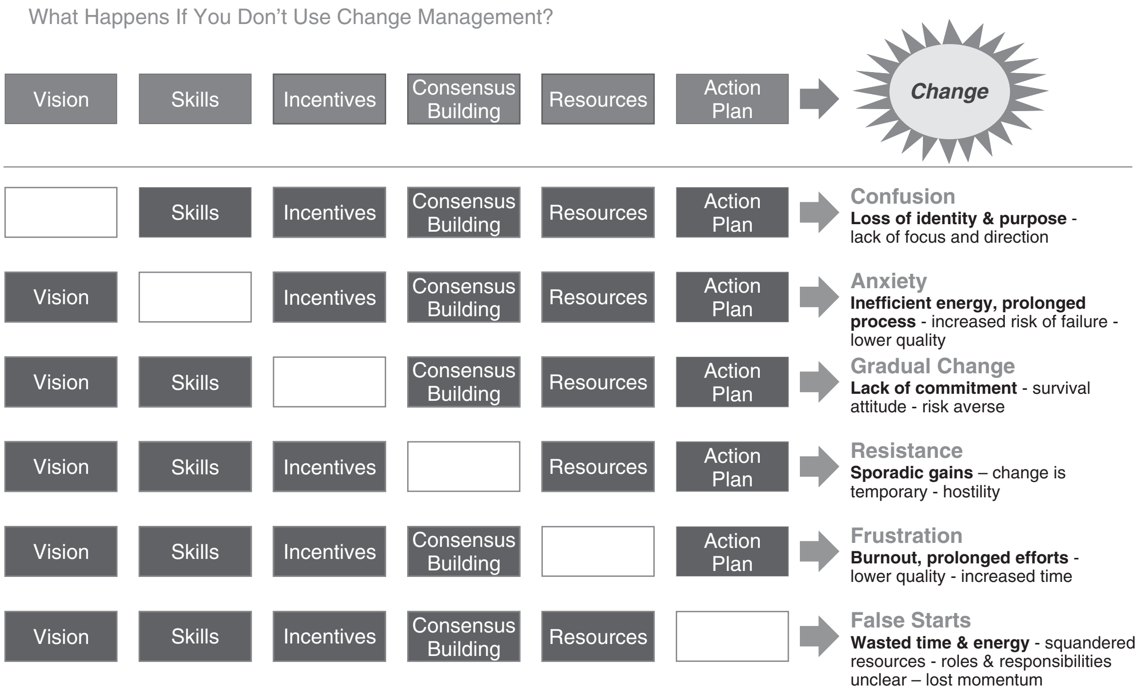

Figure 16. What happens if you don't use change management?

In considering how they may adopt, or otherwise benefit from, the best practices presented here, public transportation agencies are encouraged to keep in mind that complete mastery or internalization of each and every practice is not required to have greater success with technology. First, few if any, of the most successful agencies follow *all* of these practices. The more of them an agency can utilize, the better, but even adopting a few of them should improve technology use. Second, it is impossible and unnecessary to simultaneously and fully adopt and carry out all of the recommended best practices. Be prepared for it to take time to "phase in" these methods. Also be reassured that the effort—the *process* of promoting consideration of these practices at a given transit agency—is useful and productive in its own right. In this sense, consideration of best practices represents the beginning of an unending process of continuous improvement rather than a static "finish line" or finite end point.

2.2.3.1 10 Key Considerations for Technology Implementation

The following were identified as ten key considerations for technology implementation by the participants in the August 2006 transit agency focus group. Although consistent with the recommended best practices, which appear in later sections, this list does not consist of best practices, per se, but rather includes advice, observations, and conclusions. This list does not encapsulate the specific recommended best practices described in Sections 2.2.3.1 through 2.2.3.7. Rather, these 10 considerations include overarching observations that relatively successful public transportation agency technology adopters feel are important. In that regard they serve as a preface to, rather than a summation of, the specific best practices described in Sections 2.2.3.1 through 2.2.3.7. The 10 considerations are the following:

1. **Institutional and organizational issues are the most important factors in technology planning, procurement, and deployment.** The capability of the agency to provide leadership and vision throughout this process will significantly influence whether or not the technology deployment is successful, as will having a clear strategy or plan that governs how technology will be considered in the future. Organizational culture and structure are key factors in successful technology deployments, both in initial deployment and long-term, sustainable, and fully successful operations and maintenance.

   No one organizational structure is appropriate to all agencies, but more generally, it is clear that technology deployments are enhanced through organizational arrangements that do the following: (1) Consolidate, or at least closely coordinate, all technology-related planning and investment activities within the organization, ensuring that individual technology decisions are made in light of overall agency objectives and in recognition of the relative priority of competing technology investments agency-wide, and (2) Provide a direct connection between those responsible for an agency's technology with senior-level agency management, so as to promote management's understanding of the central importance of technology in the agency's fundamental mission, promote senior management support for technology investments (both financial and policy support, for both the initial investment and operations and maintenance), and help ensure the consideration of overall agency needs and objectives when making individual technology investment decisions. One such organizational structure is to consolidate agency-wide technology activities under a CIO or CTO who reports directly to the agency's GM or CEO.

2. **Not everyone will be happy.** Agencies need to recognize that even when the most effective change management process is utilized, no technology implementation can fully satisfy every stakeholder. In some cases, the agency may have to settle for "informed consent," which will allow technology deployment to move forward without every staff person being completely satisfied with the direction. In obtaining organizational consensus, the focus should be on the agency's core business, not on extraneous or non-essential activities.

   Also, this fact should govern how much can actually be accomplished in terms of technology deployment within the period of time being considered. For example, if obtaining staff buy-in will take a certain amount of time (which it most certainly will), then the agency needs to factor this time into the schedule. This means that the agency may not be able to do everything that it planned within the initial period of time identified for the project and may need to extend the deployment and/or divide the deployment into smaller, more manageable pieces.

3. **Be brutally realistic about what the agency can and cannot do.** It is critical that an organization understand its strengths and weaknesses in planning, procuring, and deploying technology. What an agency can do should be decided based on comprehensive factors such as full life cycle costs (rather than just capital costs) and staffing needs (e.g., training of existing staff, hiring new staff with appropriate KSAs, hardware, and software).

4. **Not every agency is ready or able to procure and deploy technology.** Agency leadership must determine whether the agency has the prerequisites to handle not only the technology that will be deployed, but the change that will be required in the organization to embrace and fully integrate the technology into operations. It has been suggested by the former GM of King County Metro as well as others that "you must first understand that it is all about change, and the technology vision allows the organization to be successful in the mist of this change." Prerequisites are discussed in detail in Section 2.3.

   Evaluation of an agency's ability to procure and deploy technology must also take into consideration the degree to which the process of change has been embraced by the agency and communicated by senior management. As adapted from John P. Kotter's "Why Transformation Efforts Fail," the eight stages of creating major change within an organization are as follows:[72]

   - Establishing a sense of urgency,
   - Creating the guiding coalition,
   - Developing a vision and strategy,
   - Communicating the change vision,
   - Empowering broad-based action,
   - Generating short-term wins,
   - Consolidating gains and producing more change, and
   - Anchoring new approaches in the culture.

   This approach was taken by King County Metro in 1993, resulting in Metro's readiness and willingness to move forward with nine specific technology projects.

5. **An agency should focus on quality over quantity in a technology project.** This means that an agency should undertake fewer technology projects or projects with fewer technologies, rather than do a poor job on a number of different projects at the same time. This can mean dividing a project into smaller, manageable pieces and being realistic about deployment time frames. Often, this can be difficult to achieve, given influences such as pressure from politicians and the public. Constant commitment throughout the project will be necessary no matter how small the project pieces are.

6. **There are two distinct dissemination challenges within the transit industry: doing a better job of getting the right information to the right people using the right channels, and providing an independent and trusted source of information (e.g., *Consumer Reports*®).** Overcoming these challenges does not mean that agencies are ready to benefit from information being provided, and that must be considered in information dissemination. Section 4.2 discusses several approaches to improving information dissemination throughout the transit industry.

7. **Success does not automatically self-perpetuate.** It requires continuous commitment and effort, including making hard decisions, recognizing and paying in-house experts, and monitoring and optimizing technology operation and technology use.

8. **Recognize that public agencies are in the early stages of an industry revolution.** SE is being used across the industry to ensure that technology projects are conducted in a logical way that encourages success. The SE

[72] J. P. Kotter, "Why Transformation Efforts Fail," *Harvard Business Review* (March–April 1995), p. 61.

process identified in the FTA National ITS Architecture Policy on Transit Projects provides many benefits:

> First, using this type of structured approach will reduce the amount of time necessary to move from project concept through deployment and full operation. Second, system users' needs will be met by using such an approach. Third, this approach will reduce the costs of deploying systems. Fourth, this approach will ensure that the latest proven technologies are used. This is because technology alternatives must be developed as part of the process, and the most appropriate and mature technologies may be chosen if they best meet the goals of the project. Fifth, using a systems engineering approach will reduce the number of changes required as the system is being developed and implemented.[73]

Agencies that have begun to embrace SE are going through major growing pains. To assist agencies, there are many examples of other industries that use this approach, such as private businesses and international public transport agencies.

9. **It is not the technology and data themselves that are important; it is what an agency does with them.** This key to success requires two major efforts: (1) the development of a plan or strategy to manage, analyze, and use the data generated from the technology and (2) the conversion of data into useable information. This plan/strategy should be developed as part of an overall technology plan during the technology planning process. Resources necessary for these two major efforts (hardware, software, and staff) must be defined. Industry experience shows that this data plan often is not included as part of an overall technology strategy and not considered until after the deployment. At the deployment stage, an agency should already have processes and procedures in place to manage, analyze, and use the data. These processes and procedures can be refined as the agency gains more experience with the technology, but they must be defined very early in the technology deployment continuum. Further, the tools that can be used by various levels of agency staff to analyze the data and turn the data into useable information should already be in place well before the technology is deployed.
10. **ROI analysis must be realistic and comprehensive (e.g., account for life cycle costs, technology replacement, and so forth) and may need to include both objective and subjective assessments.** Further, ROI analyses should recognize the value inherent in an agency's data and other assets (e.g., facilities and rights-of-way). These are often overlooked in ROI analyses. For example, agencies may have the capability to "sell" their real-time information to information service providers (ISPs) that provide regional traveler information systems.

The following subsections provide additional information regarding each of the 10 considerations. The categories that are covered in these subsections are institutional, financial, procurement/contracting, technical, organizational, and operational and maintenance practices.

2.2.3.2 Institutional Practices

Institutional and organizational issues are often the most challenging issues to address in the planning, procurement, and deployment of technology. In this project, institutional issues were the most commonly cited obstacles. Institutional issues are not only the most problematic issues; they are central to every single technology project.

The interviews and literature review conducted as part of this project and discussions held during the focus group in August 2006 identified several best practices for addressing institutional issues.

Note that neither the discussion of institutional best practices presented here, nor the discussion of organizational best practices presented in Section 2.2.3.6, includes any given practice directly referencing "change management." This is not because change management is not critical (it absolutely is), but rather because change management is an overarching activity or consideration rather than an individual best practice, per se. A number of the specific best practices in Sections 2.2.3.2 through 2.2.3.7, such as involving a wide range of stakeholders, describe components of an overall change management approach. Readers are directed to Section 2.2.2.2 for a discussion of change management as an overarching technique or strategy.

A senior level technology "champion," that is, a senior manager who believes in technology, is necessary to lead an agency from planning through deployment. According to the interviewees, the literature, and the participants in the August 2006 focus group, a "champion" is perhaps the most important element of a successful technology deployment. The former GM of King County Metro defines five critical traits of a technology champion: (1) has a vision that is focused on the technology necessary to achieve the overall corporate vision; (2) has passion and emotion; (3) can articulate the vision; (4) can use common language to discuss the vision with many different stakeholders; and (5) can articulate the vision repeatedly anywhere and at any time.[74]

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[73] Multisystems, Battelle, and Wilson Consulting, "Session 5: The Systems Engineering Analysis Requirement," instructor's guide for National Transit Institute training course on complying with the FTA's Policy on ITS Architecture Consistency (New Brunswick, N.J.: September 2002), p. 83.

[74] P. Toliver, "Critical Success Elements to Surmounting Challenges to Technology Adoption in King County, WA," presentation at the National Leadership Summit on Surmounting Challenges to Technology Adoption (Irvine, CA: August 29, 2006). (See p. A-9 of Appendix A to this report for a summary of this presentation.)

Utilize practices and organizational structures that promote coordinated, agency-wide technology planning and prioritization and which link technology investment decisions directly to overall agency strategy. Better technology planning and decision-making—especially decisions about competing investments that benefit different user groups—are obtained when responsibilities for technology throughout the agency are consolidated into an IT department led by a CIO or CTO, or when the agency is otherwise structured to *require* (not just encourage) coordination of technology activities. Consolidation of technology planning and implementation—either via a single, agency-wide IT department or via other mechanisms that soundly link technology activities carried on throughout the organization—promotes synergy, sustainability (long-term supportability), and efficiency. Such structure or processes also help promote more strategic and effective decision-making and prioritization of technology investments by considering each individual investment in light of the full-range of technology needs faced by the agency. In addition to consolidation/close coordination of technology activities through the agency, it is important to directly link that consolidated technology responsibility to the senior-level agency management. That link promotes understanding and support for technology on the part of management; it also helps ensure that technology investments and the priority/sequence of competing technology investments are made within the context of the overall agency direction and strategy.

The logic/rationale for technology investment must be made explicit and must be simple and direct. This best practice refers to justifying the procurement and deployment of technology using the most appropriate and defendable methodology and being able to describe that rationale to decision makers simply. For example, if all costs and benefits cannot be quantified as part of a cost-benefit analysis, a utility-cost analysis may be the most appropriate approach to justifying the procurement of technology. Once this analysis is completed, the analysis results can be explained to decision makers in simple terms (e.g., citing the utility/cost ratio for each technology or project being considered).

An ROI analysis is necessary and should take into account both quantitative (e.g., real costs and quantifiable benefits) and qualitative (e.g., customer satisfaction) factors, if appropriate. Different approaches to establishing ROI are necessary depending on whether the agency is making customer-oriented investments (e.g., real-time DMSs) or back-office investments (e.g., a payroll system). There are technology investments that will involve both customers and the agency. In this case, the ROI analysis could include customer surveys as well as an analysis of a reduction of non-revenue miles (for deployment of an AVL system) or a reduction of parts inventory. Further, the ROI analysis should be analogous to those conducted by the private sector.

There are numerous methods that can be used to perform ROI analyses. The quantitative methods that have been used most frequently include the following:

- **NPV** determines whether a project will produce a net benefit.
- **Benefit/cost ratio** is a way to demonstrate how much benefit is created by a project as a percent of the amount invested.
- **Marginal benefits analysis** determines the ratio of the benefit to the expenditure for the marginal difference between projects. This method compares the additional cost of an ITS technology to the additional benefit of a technology. This allows the comparison of multiple projects or technologies, whereas other quantitative methods do not indicate whether one project or technology is marginally better than another. For example, the benefit/cost ratio method compares one project's benefits to its own costs. It does not provide a method for assessing more than one project.

According to "Cost/Benefit Analysis of Public Transport ITS in the U.S.,"

> The two most prevalent qualitative methods are utility-cost analysis and the break-even approach. Each assumes some degree of cost calculation, together with different levels of qualitative assessment of benefits. The break-even approach is a way of explaining costs and benefits to lay audiences. It is also useful when a precise numerical value cannot be determined. A utility-cost approach requires, in the absence of monetary values of benefits, that weighted indices of effectiveness be created. These indices, registering the utility of ITS actions to meet goals, objectives, and/or evaluation criteria, are created using subjective reasoning, often based on consensus input from informed and interested parties. Utility criteria can account for how well ITS technologies address the needs of the provider, customers and/or positive externalities.[75]

An example of an ROI that includes both quantitative and qualitative factors is a utility-cost analysis. "The utility-cost analysis method considers key subjective factors in the assessment of which ITS project or technology is best to deploy. The overall agency goals and objectives are taken into account, along with how well each technology/project being considered will meet those goals and objectives. Coupled with the technology/project costs, a utility-cost ratio is developed for each technology/project."[76]

An example of an ROI for back-office systems is one conducted by BART as part of their BAP. BART's "Projected

[75] Schweiger, "Cost/Benefit Analysis of Public Transport ITS in the U.S.," p. 2.
[76] Ibid.

Inventory Analysis" calculated the projected savings due to overall reductions in inventory purchases whether from capital or operating funds.[77] This analysis included the following:

- A baseline analysis that calculated projected inventory with no improvements in systems or procedures,
- One case that projected inventory assuming improved systems and procedures, and
- One case that projected inventory turns (inventory used/inventory on hand at end of the year) required to eliminate capital funds and keep the same level of operating purchasing funds from the baseline.

Know what your customers need and want. First, all customers need to be considered, including riders, taxpayers, policy makers, employees, and media. Potential customers should be considered as well. Second, part of the technology vision mentioned earlier in this section should include meeting or exceeding customers' needs through the use of technology.

An example of determining customer needs for technology was provided in *Customer Preferences for Transit ATIS: Research Report.*[78] In this study, 12 workshops in 4 metropolitan areas were conducted in November 2002 with 284 transit customers. Several questions were addressed, including the preferred methods for delivering information to transit travelers. FTA was particularly interested in transit rider preferences in advanced technology information services. The results of this study indicated that riders prefer paper-based information and traditional wayside signage (e.g., schedules, maps, and fares). Inaccurate information was perceived as worse than no information, and high-quality traditional forms of information were considered more important than advanced technology approaches. Awareness of advanced technology transit information services was low, even in areas where they are available, suggesting that transit agencies need to promote their existing information services more. The results of this study indicate that in the four areas where the workshops were held, providing technology-based information was not necessarily as important to customers as was providing quality information in more traditional ways.

Another example is the work that was done by King County Metro in 1993 to identify customers' needs (some of which could be addressed by technology). Before customers were asked about what they needed, part of King County Metro's technology vision was to "meet or exceed customers' needs and desires."[79] Metro defined customers as riders/users, taxpayers, policy makers, employees and the media. Some examples of what customers said they wanted included:[80]

- Convenient and user-friendly access to up-to-date and accurate information;
- More information about routes, schedules, fares, and how to ride the bus;
- Information about bus arrival times at stops (on time or not?);
- Easier fare payment; and
- Employees who had easy access to information they needed to do their job.

Ensure that you have a fully supportive community by selling pride in having a system that uses "advanced technology." Community support for transit overall, and especially for the expenditure of transit resources on technology can significantly affect the success of technology deployment. Several interviewees, including King County Metro, Portland TriMet, and OUTREACH, as well as participants in the August 2006 focus group indicated that the overall support for public transportation and general support for advanced technologies in their regions contribute to their success. They, and agencies such as the Cape Cod Regional Transit Authority, also point to the presence of IT-oriented businesses and universities in their communities and agency partnership with these entities, as important factors.

Know your agency/board culture/climate and commit to educating and building trust and support among your board members. To "sell" technology to an agency board, it can be helpful for the technology champion to focus on board members individually (as unique customers) and address their individual issues regarding technology in order to ensure that each member will be fully supportive. If needed, the agency should provide technology education for board members. Technology training resources are available for board members and senior management through NTI (http://www.ntionline.com) and the U.S. DOT Professional Capacity Building Program (http://www.pcb.its.dot.gov/le_search.asp?SearchRequested=True&PageID=res_curric&ExpandInfo=).

Also, it is critical to understand the culture that the board reflects. The King County Metro interviewee noted the importance of "organizational self-image." Success in technology deployment is aided when an agency perceives itself as willing to take some risks and dedicated to improvement by utilizing the best available technology. One U.S. agency interviewee stated that "if you can't get your board and the staff to come along, you're dead."

[77] "Bart Projected Inventory Analysis," ROI spreadsheet provided by R. Cody, BART (October 2006).

[78] Battelle Memorial Institute and Multisystems, Inc., *Customer Preferences for Transit ATIS: Research Report,* FTA-OH-26-7015-2003.1, prepared for the FTA (Washington, D.C.: U.S. DOT, August 8, 2003).

[79] P. Toliver, "Critical Success Elements."

[80] Ibid.

Agencies endeavoring to "win over" a board not historically supportive of technology investments should be prepared for the process to take considerable time and effort. Strong presentations that clearly explain the business rationale for specific investments is critical. As the interviewee from the Cape Cod Regional Transit Authority noted, "I'm able to succeed with the board because they trust me. . . . When presenting new ideas, do a 'mock-up,' show things using pictures." The Ann Arbor Transportation Authority has "a whole program to educate and build support among the board, the chief executive officer, and general manager." This agency also noted that "building support has been key," along with anticipating turnover in board members and the need to periodically re-educate. These activities have included taking different individuals to APTA and ITS America conferences. The Ann Arbor Transportation Authority's executive director emphasizes that "you have to have the ability to make a convincing presentation to the board; if you do not have the funding, you have to start working to get it."

Ensure that all of the stakeholders are involved in the project, especially in the initial planning and design stage, and identify how the project will benefit participants. It is important to include all of the stakeholders in the planning process to ensure that their needs will be met by the new technology. This may include maintenance personnel, drivers, customer service, and operations planning representation. Involving these departments early on facilitates their cooperation later in the deployment process. Additionally, it is important to involve other agencies that have a stake in the project (such as metropolitan planning organizations and regional FTA staff) in order to ensure that their needs are being met as well.

For example, involving drivers in the installation and implementation of on-board systems is critical to success. It is important for drivers to "buy into" the system since they are a key component of agencies' operations, and they have to use the technology as much as or more than any other transit staff member. Drivers sometimes experience "big brother" fears, particularly with the installation of AVL systems that track their locations. Thus, their involvement or the involvement of their peers will help them understand the benefits that will accrue to them, such as being able to contact dispatch immediately in case of an on-board emergency (and knowing that dispatch can communicate their exact location to law enforcement).

It may be necessary for an agency to demonstrate to project participants that the ITS application will benefit them directly. Although it may be difficult to quantify these benefits, providing at least a description of how participants can use the system to improve their operation can greatly increase their willingness to participate in the project.

Have an appropriate strategy for unions, specific to your agency. Technology acceptance by unions is critical to successful deployment. Participants in the August 2006 focus group offered recommendations on handling unions regarding technology adoption and deployment. First, "rank and file" union input is most useful in developing requirements. This best practice is an extension of the previous best practice that describes including all stakeholders in technology planning, procurement, and implementation. Further, it was recommended to "sell" the rationale to unions, but to be prepared for continued resistance. Second, focus on union leadership for overall buy-in.

Leverage partners to get your program going. A good long-term practice, utilizing partners, is especially important in the early stages of a technology program when support and budgets are especially limited. Potential partners include colleges and universities and technology companies, including those who are and are not currently vendors of transportation-specific or transit-specific technologies. The Ann Arbor Transportation Authority identified partnerships with vendors on demonstration projects as one of the keys to getting their technology program established. OUTREACH also identified their ability to develop partnerships with major private industry players as a key to their success.

Further, ITS solutions have the potential to foster better cooperation and coordination among project participants. ITS have been shown to improve both the cooperation among project participants (inside and outside an agency), as well as the consistency of information available to all participants. However, it is possible that making an effective connection among participants may require that new procedures are established.

Pool resources among agencies across common needs and/or projects and be open to working with new agencies and staff. This best practice can be applied in a region, state or nationally. An outstanding example, now in development, is the Utah Transit Authority (UTA) proposal for an applied technology center. According to the October 7, 2006, "General Manager Foundation Meeting Report" for the UTA-led Applied Transit Technology Center:

> Over the last several months the UTA, in collaboration with APTA and the PT [Public Transportation] Forum, has been circulating a proposal to organize a consortium among transit agencies to foster the application of technological innovation into the operations of American transit agencies, especially medium and small properties that cannot afford large technical and engineering staffs. The primary focus is on adapting existing technologies to the transit environment through testing, demonstrating, evaluating and disseminating results and providing support for adoption of such innovations by transit agencies. The intent is for

> development of joint deployments among transit properties, sharing the costs, risks and intellectual resources to insure a successful implementation in all participating agencies. In addition, lessons learned would be shared with all other transit properties.[81]

As of January 2007, UTA and their partners are developing the applied technology center concept and intend to ultimately seek federal funding support.

Funding from different agencies may mean that an agency is faced with multiple reporting requirements, as well as staff from other agencies with whom they previously have not had a relationship (e.g., when a transit ITS project is funded by a highway department). Thus, an agency needs to be prepared for dealing with new external staff and requirements.

Finally, for projects that involve multiple agencies, developing memoranda of understanding can help clarify each participant's responsibilities. Without some type of agreement in place to ensure that each agency will fulfill their responsibilities, technology projects may face delays. Further, establishing agreements can assist in providing ongoing support for the project.

Sometimes project participants can change, so it is important to be flexible. While ideally, all of the participants involved at the outset of a project would remain with the project until the end, this is not always the case. The ability to recover from unforeseen events is an important skill to foster with any ITS implementation, particularly those that involve a number of different participants.

2.2.3.3 Financial Practices

Fully consider and be creative in developing revenue opportunities associated with transit assets and technology. Revenue-generating opportunities include not only advertising, but also innovative P3 programs. For example, WMATA has initiated a technology P3 program "to improve customer service, security readiness, and revenue generation opportunities."[82] As of November 2006, WMATA is reviewing proposals from vendor teams to provide an integrated customer communication system. According to WMATA, it "has three goals for this initiative. The first goal is to provide transit customers, represented by the 1.4 million daily transit trips, with real time, high quality accurate information to facilitate their travel. The second goal is to generate a source of non-fare box revenue as reflected in the market value of the WMATA customer base and their connection to the 3.8 million households in the metropolitan area. The third goal is to enhance customer security."[83]

Creativity and innovation can pay off in terms of funding. Agencies can also benefit from being creative and innovative in obtaining funding for their ITS deployments. For example, multiple funding sources may be combined for a project, or new funding sources might be explored. There are many traditional and untraditional sources of funds that should be considered for technology projects. An example of a traditional source is Congestion Mitigation and Air Quality Improvement (CMAQ) (SAFETEA-LU Section 1808) funds, and an example of a untraditional source is New Freedom funds (49 USC Section 5317, CFDA #20.521).

Further, P3 opportunities can complement limited federal funding. In addition, non-traditional sources of funding should be pursued. For example, a private, nonprofit demand-response transit agency in the greater Philadelphia area was able to partner with the McDonald's Corporation to fund the purchase of new vehicles.

Finally, agencies should try to explore innovative P3 opportunities for services, especially in the case of ATIS. Such steps can help in generating funds from advertisement or other sources, such as charging users for some premium/personalized services.

Be aware of the provisions of the Buy America policy. As with all purchases, transit agencies need to be aware of Buy America provisions when making technology purchases. The following provides a brief description and history of the Buy America policy: "Originally passed by the U.S. Congress in 1978 as part of the Surface Transportation Assistance Act, the legislation authorizing FTA's Buy America policy reflects an attempt by Congress to protect the U.S. labor force and heavy industry from foreign competition. The original legislation, which specified a preference for products produced, mined, or manufactured in the United States, subsequently has undergone several major amendments, including the Surface Transportation Assistance Act of 1982, which required that all steel and manufactured products used in FTA-funded projects be produced in the United States."[84]

Agencies should also be aware that changes are currently being debated to the Buy America policy that could specifically impact technology purchases. These changes pertain to the definition of "microprocessor" (and will therefore impact computer and other technology component purchases) and to the classification of individual purchased items as "end

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[81] Applied Transit Technology Center, "General Manager Foundation Meeting Report" (October 7, 2006).

[82] WMATA, "Washington Metropolitan Area Transit Authority (WMATA) Amended Request for Expressions of Interest (EOI) for Technology Public-Private Partnerships—June 19, 2006" (Washington D.C.: July 20, 2006), p. 3, www.wmata.com/bus2bus/contracting/iccs_reoi_v2.pdf.

[83] Ibid, p. 4.

[84] Hidalgo & DeVries, Inc. and Frances Kernodle Associates, Inc., *U.S. Non-Rail Vehicle Market Viability Study,* FTA-001, prepared for the FTA (Washington, D.C.: FTA, U.S. DOT, January 19, 2006), p. 42.

products," including designation of systems, components, or subcomponents as end products. Readers are encouraged to monitor the final resolution of these issues (ongoing at time of publication) through the FTA's second notice of proposed rulemaking of November 30, 2006.

Consider that ITS projects include many (sometimes unanticipated) costs. It is important for agencies to realize ahead of time that costs will arise throughout the project deployment, as well as during everyday operations. Typically, ITS deployments include initial start-up costs, capital costs, ongoing maintenance and upgrade costs, and costs associated with staff time and effort (e.g., time managing the project, attending meetings, and approving invoices).

Further, agencies should not expend all funds in a project; some funds should be held for unexpected circumstances. As mentioned previously, agencies should "expect the unexpected" when deploying new technologies. Agencies need to be flexible, realizing that everything will not run smoothly. Agencies need to have the ability to add enhancements or fix problems when they arise. Keeping contingency funds for such occurrences can allow the agency to cope with these situations.

2.2.3.4 Procurement/Contracting Practices

Understand what vendors have to offer and maintain reasonable expectations. Many transit systems depend heavily on vendors for specific information on transit ITS applications. In many cases, transit ITS solutions have been oversold or agency expectations have been unreasonably high. This can lead to agency ITS needs not being met by product vendors. Further, in the implementation process, it is critical that the agency conduct a design review with the vendor that ensures that there is complete agreement between the agency and the vendor as to what the vendor will provide and what the agency expects from the vendor.

This understanding should include the vendor's experience with similar deployments. Agencies must check the vendor's track record and ensure that they have the necessary experience to deal with the specific system and issues associated with that agency. If a vendor does not understand an agency system, they may not be able to provide the support that the agency needs. Therefore, it is important to check vendors' references, particularly from agencies that have similar characteristics to the procuring agency. Agencies may want to visit sites where the vendor has installed similar systems.

Finally, if an agency is using an outside consultant to assist with the procurement, they risk giving up control to the individuals who understand technology unless someone at the agency who is technically knowledgeable is involved in the procurement. Agencies should think about having a staff member who can deal with the technical issues associated with the procurement, so as not to rely solely on consultants and/or vendors for technical support.

The procurement process sets the tone for the whole project. Agencies need to realize that a sound contract does not necessarily mean that the project will be smooth and without conflict. They must establish a good working relationship with their vendors. Management needs to understand enough about the technology to ask the right questions. Outside assistance can be helpful in this regard, but if an agency is using outside assistance, it should consider retaining the assistance through the entire planning, procurement, installation, and testing process.

Procurements should cover optional items that an agency may wish to purchase in the future. Often, it is a challenge to make decisions about every conceivable feature or element of technology that is desired. If there are open questions at the time of procurement, agencies should include a description of potential future requirements and request that each proposer provide a price for those items or services. This will ensure that the agency can exercise that option at a later date for a reasonable price.

Consider performance-based contracts, including incentives and penalties. One way of avoiding problems later in the ITS deployment is to write performance-based contracts with vendors. For example, agencies can develop project milestones, with payment to vendors dependent on reaching these milestones. In this way, vendors have an incentive to do a good job and meet the project schedule.

Further, agencies should ensure that specific documentation is included in vendor contracts. Documentation is important, and agencies should insist on receiving adequate documentation from vendors. Documentation may include operational and maintenance manuals, system administration operation manuals, communication protocol manuals, training materials, or other documents, such as design review documentation, installation design documentation, and acceptance test procedures documentation. One reason to ensure that adequate documentation is received is that staff turnover is inevitable, and having proper system documentation will help new staff become more quickly acquainted with the technology.

2.2.3.5 Technical Practices

Develop a technology strategic plan for the entire organization. Nearly all of the organizations interviewed and those organizations represented at the August 2006 focus group utilize either a strategic plan dedicated to technologies or a general organization strategic plan that includes technology. Development of a strategic plan must involve both IT and project staff, and should include some level of participation by senior management. A strong strategic plan identifies the problems to be solved, the needs to be addressed, and the business rationale for specific investments. It is critical that organizations move from a totally reactive position, which is typical when there is no overall plan or direction, to a proactive, strategic one. According to the WMATA interviewee: "In the past, decisions were driven by opportunities or circumstances; for example, putting in a new rail service, old technology systems failing, etc.—and that's how our first AVL system was implemented; we simply were looking to replace the dispatch system and AVL seemed to be the next generation. In this mode, technology decisions were driven more by equipment replacement cycles than by business needs, which is what they should be driven by." WMATA recognizes that many agencies feel that they do not have the time or funding for strategic planning but insists "You have to make time to plan your future."

Recognize the requirements of the FTA National ITS Architecture Policy on Transit Projects. Since compliance with the requirements of this policy will be discussed and reviewed during an agency's triennial review, it is important that the agency factors the policy into planning and designing a technology project. One interviewee noted that, especially in the past, FTA had funded a lot of technology projects that were not well thought out by the local implementers, that did not include a concept of operations, and that did not include a consideration of project life cycle costs. This interviewee commented that there has not been enough "enforcement" of the FTA National ITS Architecture Policy and that many agencies' architecture efforts have merely been a "check off" and not a meaningful exercise: "People [agencies] have figured it out, and they're thinking 'why should I develop an architecture and use a systems engineering process?' Or, more importantly, why should they do it in a resource-intensive, meaningful manner rather than simply go through the motions necessary to demonstrate compliance?"

Start small and expect a long, incremental process. Understand that developing a sound technology program and implementing good projects takes time and that it is important to start small. According to Portland's TriMet:

> It's an evolution; you can't go from '0 to 60' in one step. Take small steps. Pick a small number of simple things and focus on them to get really positive results that can be used to build support for technology investment and which provide an experience base for more extensive implementation. When starting out, go for things with immediate pay off, then ramp up the level of investment and the size of the projects when the value of technology is more clear and support has been developed.

The Ann Arbor Transportation Authority echoes this advice: "Do one thing at a time and do it well, then go on to the next thing. Identify a single key project or program to focus on at any given time." UPS characterized this same need for focus as "moving from trying to do everything for everyone to doing the right things for the right people."

Timelines directly affect when benefits can be realized and the life spans of many technologies (sometimes by the time the technology is implemented, it is obsolete). As the King County Metro interviewee noted, technology is constantly changing and is therefore a "moving target," and long project timelines compound the challenge. The OUTREACH representative stated that "by the time a project is fully up and running, it's all obsolete and needs to be upgraded." The COTA (Columbus, Ohio) interviewee summarized the situation as "chasing your tail."

When analysis supports it, use COTS technology products. Interviewees and participants in the August 2006 focus group consistently recommended that transit agencies use COTS products to improve the success of their technology implementations, and, indeed, this seems to be the "common wisdom." The recommendation here, however, is that agencies should carefully evaluate their technology options—which include COTS, developing a fully custom product, and outsourcing the function entirely (e.g., using an application service provider for a specific software). Agencies should then select the option that best suits their needs and capabilities. When a COTS product is available that requires little or no modification, it is probably the best choice. When significant modification of a COTS product is needed and agencies have good in-house development capabilities (to either develop or supervise a consultant's development efforts), a fully custom product may be the best choice. If in-house development is pursued, the agency should use an in-house development team as a commercial developer would and carefully consider the potential intellectual property rights and licensing implications.

One of the advantages of using COTS products—when such a product is found to meet an agency's needs with very little or no modification—is that it is often easier to support and maintain over the long term. As part of a larger user base, an agency using a COTS product can take advantage of manufacturer bug fixes, recalls, and upgrades. In contrast, when dealing with either highly customized COTS products or full custom products, not only is the agency responsible for the initial development effort, they must also support all subsequent maintenance and upgrades. One interviewee from OUTREACH, a paratransit provider, indicated that they have had success using not just "public transportation" COTS products but "general market" COTS products.

One of the ways for an agency to significantly increase its ability to benefit from a COTS strategy is to minimize the degree of customization by altering its requirements to fit the software, rather than the reverse. BART's CIO, Robin Cody, reports that this is his first consideration after performing a gap analysis (in which the capabilities of COTS products are compared to agency requirements). Mr. Cody believes that there are many cases in which some agency-specific requirements reflect "they way we've always done it" rather than "the only way it can be done." In such cases, altering some agency approaches to take advantage of COTS products may be less painful—especially considering long-term maintenance and support—than customizing the COTS software. Mr. Cody indicates that his goal is generally to restrict customization to no more than 5 percent on any given product.

Writing "technical" specifications may not provide the results desired. Using either functional specifications or a hybrid of functional and technical specifications is identified as the best way to obtain the appropriate system within a specific budget. Functional specifications, based on functional requirements, can give the vendor the concept of what the agency wants, while at the same time challenging the vendor to design a workable solution that may differ slightly from the agency's requirements. In writing specifications, even functional ones, the full range of needs and required functions needs to be considered. Many agencies will benefit from consultant support in developing specifications.

Technology changes fast, so agencies need to make sure that their system can be easily upgraded. In today's changing environment, it is important to ensure that an agency's ITS system can be easily expanded as technology evolves. For example, an agency may want to make sure that their system has "flash" capability or can accept software upgrades via remote access software. These tools may greatly improve the ease with which system upgrades can be made.

Agencies need to reserve adequate time and resources for data preparation. Field experience shows that agencies' databases usually need a significant amount of "scrubbing" before they are compatible with new software. In some cases, data interfaces need to be created between legacy systems and new technology. Agencies often underestimate the amount of time it will take to prepare their data for entry into a new system.

2.2.3.6 Organizational Practices

Form a technology guidance committee composed of senior management. WMATA cites the formation of its Technology Advisory Committee, composed of the senior managers from each department, as one of the two events that led to an organizational "breakthrough" in how it approaches technology. According to the UPS representative interviewed for this research, UPS's current coordinated approach to technology investment, which links investments directly to business needs and overall strategic direction, also began with the development of an

> executive steering committee consisting of four cross-functional, senior-level executives [who] set strategic direction for IT; establishing priorities and funding levels. This team met regularly during the late 1980s and early 1990s while UPS's IT capability was built. By 2001, the committee transitioned to an overseer role, providing input on the company's long-term technology strategy. As the executive steering committee became less active in IT governance, it was replaced with the Information and Technology Strategy Committee (ITSC) composed of 15 senior managers from all functional areas within the company. The ITSC was chartered with studying the impacts and application of new technologies and understanding near-term technology direction.

The Ann Arbor Transportation Authority reports that "general management is very involved in our technology planning process; we meet every Friday to go over hot topics." Finally, Capital Metro has a team of senior managers guiding its ITS efforts.

Consider consolidation of technology responsibility. As described above, a single guidance committee including both senior management and representatives from various business units within the agency is one way to promote synergy, efficiency, and inclusiveness in technology planning and implementation. Another method to promote an agency-wide perspective and approach to technology planning and implementation (i.e., one that transcends individual business units) is to consolidate the agency's technology activities under a single department, led by a CIO or CTO. Use of such a structure does not eliminate the need for the aforementioned technology guidance committee, but it is quite appropriate to use the two methods together. In this case, the IT department (or similar entity) would be a key participant on the interdepartmental guidance committee.

The ITS department or ITS staff should have a direct line to the agency GM and should routinely interact with other departments/staff. Having direct communication with the highest management level in the agency will ensure that technology initiatives have high visibility within the agency and are fully supported at the highest levels. Further, engineering/IT expertise should be linked with planning/project management expertise. Not only should these groups partner in developing a technology strategic plan, but they should also work closely on a permanent basis. This partnering could occur via a committee or task force, or it could entail a permanent change to the organizational structure, as was done at WMATA, where these two groups were merged into a single division with a single manager. WMATA cites this change as one of the two breakthroughs that revolutionized their approach to technologies and thinks that the combined group promotes synergy and a holistic perspective. Technology staff must maintain contact with other agency staff (e.g., planning), even when a technology project is not underway, so that they are fully aware of agency initiatives that may involve technology at some point in the future.

Agencies need to train in-house personnel to effectively supervise consultants. This best practice involves not only training, but also being able to assess the KSAs of agency staff tasked with managing technology and technology consultants. An agency must be realistic in assessing its in-house capabilities and tailor its strategies appropriately. This may mean that the agency buys the needed services. Another element of determining and using in-house capabilities is not underestimating the value and need for training.

Assessing KSAs can be accomplished using job analysis,

> a procedure for identifying the criteria for or performance dimensions of a job. A thorough job analysis documents tasks performed on the job, the situation in which the work is performed, and the human qualities needed to perform the work. . . .
>
> Job analysis is accomplished by collecting data that describes a) observable or otherwise verifiable job behaviors performed by workers, including what is accomplished as well as the technologies employed to accomplish the end results and b) verifiable characteristics of the job environment with which employees interact, including physical, mechanical, social and informational elements.[85]

The NTI course, "ITS Staffing," includes a toolkit that can assist in performing a comprehensive job analysis to determine the KSAs of in-house staff.

Further, the agency must make a commitment to technology education, particularly in light of assessing the KSAs of existing staff. This commitment involves learning about technologies through reading and attending conferences (APTA and ITS America were specifically noted) and consulting agencies experienced with technology implementation. The TriMet interviewee notes that agencies should "work hard to really understand what the technology can do for you; you need to move beyond a superficial understanding and the superficial appeal of the technology. Both senior (e.g., GMs) and staff level personnel need to be educated. Technology people (IT staff) really have to understand the business of the organization." WMATA considers technical capacity fundamental ("you have to develop technical capacity") and notes that it is important for the effective management of consultants. WMATA also notes that many agencies, even large ones, do not seem to have "core capacities." WMATA encourages dialogue with other agencies to "get lessons learned" because "you do not want to learn hard lessons yourself." As stated by the Executive Director of the Ann Arbor Transportation Authority, "The world is flying by. You have to get people to go to conferences, to get aware."

[85] McGlothin Davis, Inc., "Acquiring Personnel with Appropriate Skills," Session 9 of ITS course "ITS Staffing," instructor's guide (New Brunswick, N.J.: National Transit Institute, July 2004), pp. 185–186.

Agencies should anticipate organizational changes. Anticipating the organizational changes that will be necessary leading up to technology deployment is critical so that organizational disruption is minimized when the implementation is complete. For example, the implementation of an automated fare collection and revenue control system may prompt the reorganization of the revenue department or the addition of staff. These organizational impacts should be considered during the design stage so that they can be handled appropriately and well in advance of the implementation stage. This is a fundamental part of change management, which is discussed in Section 2.2.2.2.

Remove bureaucratic barriers to promotion of good ideas. Barriers in the organization that prevent innovative technology ideas from surfacing from mid- and lower-level staff need to be eliminated. Allow the various "technology buffs" throughout the agency access to those who are involved in technology planning and project evaluation. As the OUTREACH interviewee noted, it only takes one barrier or dead end to bury a good idea. That is, as the idea makes its way up a vertical chain of supervisors, it only takes one person in that chain who is not supportive to kill the idea. OUTREACH management also indicated that when developing projects they "do not let technology people report to technology people"; technology people report directly to the CEO, who has the big picture vision. Having technical people interact directly with visionary management keeps the technology people realistic and focused and provides management with an understanding of costs as the concept is developed.

Outreach should be conducted internally and externally to ensure that project accomplishments and successes are well publicized. Successes may come in many forms and may be different from an agency's original goals. Agencies should consider making external presentations at conferences, being a "peer" to help other agencies implementing ITS technologies, or other means of distributing information about their successes (e.g., press releases in local media). Internally, those involved in technology project accomplishments should be recognized, and these projects should be highlighted in agency communications, such as employee newsletters, and at local events.

2.2.3.7 Operational and Maintenance Practices

Ensure that operations and maintenance staff have input during the planning and procurement process so that the resulting system(s) satisfy the needs of the operations and maintenance personnel. Since this staff will have to "live" with the technology once it is deployed, they should have significant input into defining the systems' functionality, as well as hardware-specific issues (such as placement of hardware in the vehicle). It is also important for key staff to participate in the procurement process so that they can provide input while the system(s) proposed by the vendors is (are) being reviewed and assessed.

Further, the agency must ensure that operations and maintenance staff understand their role vis-à-vis the technology and the agency must obtain their buy-in. Understanding the positive impacts of the technology on their job functions will ensure not only their buy-in, but also will position staff as mentors for those staff who may be apprehensive about using the technology.

Implementation should include a pilot phase, in which hardware is installed on only a portion of the fleet or system and fully tested, before full installation is completed. Piloting allows an agency to work out any "bugs" in the system prior to installing hardware on all vehicles. This is particularly important since, once full installation occurs, all vehicles must be brought into the maintenance facility in order to repair problems with the in-vehicle equipment (although regular mechanical repairs may be done at the local sites).

Establish clear sign-off and acceptance procedures and a formal process to track problems during implementation and operations. Contracts with vendors should include an acceptance testing phase as part of the implementation process for new technology. In this way, the agency is not left with a system that does not function properly once the vendor has left the picture.

There are several techniques that should be utilized throughout a technology deployment in order to ensure that everyone involved in the project understands the status of the project at any point in time; the current action items, who is responsible for resolving them, and when they will be resolved; and how each issue is being addressed. This formal process can utilize simple tools, such as a spreadsheet (often called an action item list or "punch list") that notes each action item as the project progresses, the date that it is expected to be resolved, and who is responsible for resolving the item.

Technical support is very important in any ITS deployment. It is important for agencies to maintain support agreements with vendors and/or develop the necessary in-house expertise to deal with technical issues. For example, ITS deployments that include a GIS component may require ongoing staff support for data maintenance functions. Agencies' service areas are continuously changing, requiring ongoing changes to underlying GIS data. While agencies may be able to rely on vendors for some changes, they may have a need for in-house support to deal with ongoing, minor changes.

Training staff in the use of transit ITS is important no matter the size of the agency. Some ITS deployments have focused heavily on training, but many agencies have fallen short in this area. Agencies should realize that vendor training is not the only option available. Peer-to-peer training can be a very useful and cost-efficient training method. However, when using this method, agencies need to keep in mind that different operators have different needs, so they must think carefully about the transferability of knowledge. Additionally, Web-based training should be considered as it becomes available. This type of training may not take the place of individual or on-site training, but it can be a useful supplemental tool and is a cost-effective way to provide ongoing training as the system evolves.

Agencies should analyze their in-house maintenance capabilities. Agencies will need to review their staffing and budgetary constraints before implementation in order to determine whether maintenance should be conducted in-house or whether outsourcing will be necessary.

2.3 Prerequisites for Improved Technology Implementations

This section discusses the concept of agency "prerequisites" for successful technology adoption. These prerequisites describe conditions, capabilities, or assets that must be present for *maximum* technology success and to allow an agency to employ and fully benefit from *all* of the more specific best practices described in Section 2.2.3. The genesis and validation of the prerequisite concept in this study are described, followed by an exploratory discussion of the implications of "the prerequisite challenge" for the dissemination of these study findings.

Transit agencies should note that although deserving of priority consideration, prerequisites need not be the exclusive focus of initial efforts to improve technology deployment. Many of the specific best practices recommended in Section 2.2.3 can be applied in the absence of some of the prerequisites and can still help improve technology deployment. For this reason, agencies are encouraged to begin utilizing as many of the practices as possible while they work to establish all of the prerequisites for maximum success in technology deployment. Indeed, working to adopt the best practices will be helpful in cultivating the prerequisites. Overall, the purpose in identifying prerequisites is not so much to suggest to individual agencies that these factors should be their exclusive focus, but rather to suggest to those who fund technology investments that agencies lacking these prerequisites are unlikely to achieve full success.

2.3.1 Identifying Prerequisites and Their Significance

Over the course of this study, the project team began to suspect that simply knowing the "right things to do" (best practices) would not be enough for the many public transportation agencies who have long struggled to fully capitalize on technologies. This tentative conclusion was based on three observations:

- **Many best practices are known.** Not all, but many, of the individual best practices seem to be already well documented in the literature, and, most importantly, have been understood and discussed by transit agencies for a number of years. The sentiment that "we (transit agencies) have been talking about this stuff for years and nothing changes" has often been expressed in the agency interviews and other discussions that have occurred over the course of this multi-year study. Many agencies seem to be keenly aware of what they are lacking and what they should be doing, but they still can't seem to get there.
- **Some key "new" best practices require major shifts in philosophy and supporting policy.** Some of the critical "newer" practices, like SE or EAP, aren't things that an agency IT, planning or operations manager can necessarily just start "doing." These practices represent significant departures from past approaches—they're more rigorous and resource intensive—and require supporting policy. The move to SE constitutes a revolution in industry standard practice and a paradigm shift in the way agencies approach projects. Lacking the proper agency leadership and organizational culture, a technology project manager or strategic planner cannot pursue an SE or EAP approach; these approaches can be an order of magnitude more resource intensive than the traditional (much less effective) methods deeply embedded in agency standard operating procedure.
- **Many practices describe necessary "conditions" rather than actions.** A number of the "practices" which agencies and experts feel are most critical—those pertaining to organizational/institutional/cultural and other "people" issues—really describe ways that an agency must "be" to succeed with technology, rather than things they should "do." For example, the most commonly cited and seemingly most critical issues—having supportive agency leadership and a visionary project champion—are not things agencies can do, but rather are conditions, capabilities, or attributes that they must possess.

As these observations accumulated, the project team became increasingly concerned that the practices identified in this study might become "just another good report" that failed to really help the agencies most in need of help. Fueling this concern was the fact that struggling agencies not only appear to already know what they "should" be doing, they also are becoming frustrated with recommendations that lack recognition of their fundamental challenges. There seems to be a growing sense of helplessness resulting from hearing, again and again, over more than a decade, that the keys to success are the things that they do not have and can't seem to acquire. This was certainly the sentiment—expressed off the record—of several practitioners who participated in or sat in on the ITS America 2005 Transit GM Summit (the ITS America 2005 Transit GM Summit is summarized in Appendix B).

Based on these observations, the project team formulated a hypothesis. That hypothesis is that there are a number of important preexisting conditions, attributes, or capabilities that must be present at a given agency in order for the IT, planning, and operations personnel—the target audience for most of the best practices—to be able to effectively apply those best practices. This hypothesis was presented to the participants in the transit agency leadership focus group conducted for this study. The hypothesis, which came to be referred to as "prerequisites," was widely supported by focus group participants, who generally validated the three project team observations described above.

The list of prerequisites that emerged from the focus group discussion (supported by the other research conducted for this study) is as follows:

- Agency *leadership* (CEO, GM, and/or board) that understands and supports technology.
- A *vision* for how technology will permeate and benefit the agency directly linked to a realistic and phased *plan*—developed from the input of a very wide range of stakeholders—for realizing the vision.
- An *organizational culture* that supports technology and accepts change.
- A *supportive community* that values transit and supports investments, including technology investments, to improve transit.
- *Resources* or the ability to access them (e.g., through good grant-writing skills and leveraging a wide range of resources, such as partnerships).

Part of the reason that it is so difficult for agencies that lack one or more of these prerequisites to succeed at technology deployment is that these prerequisites are so interrelated. The presence of one is often a key requirement for another, and they reinforce and perpetuate one another. This leads to either a downward or upward cycle; if an agency is challenged in fundamental ways, it will probably not fare well with technologies and vice versa. Lacking a prerequisite is difficult enough, but what's worse is that it's harder to establish any one of these prerequisites if another is missing. For example, without supportive leadership, it's very difficult to establish and maintain a pro-technology, change-tolerant organizational culture. Realizing that these prerequisites are important and that they are interrelated and self-reinforcing makes the frustration and disillusionment evidenced by some agencies quite understandable.

2.3.2 The Size and Significance of "The Prerequisite Challenge"

After validating the prerequisite concept with the focus group participants and delineating the prerequisites, the project team pressed the focus group participants to speculate on the size of the prerequisite challenge—the proportion of agencies that lack prerequisites. The reasoning is that as crucial as the notion of prerequisites may be, the real significance of this finding lies in the number of agencies that are challenged in this manner. If it's a big problem for just a handful of agencies, then it is not, at an overall industry level, a very big problem, which should impact how it is approached.

Agreeing that there was no good quantitative data on the prevalence of prerequisites, the focus group participants were somewhat hesitant to venture a guess. They did agree, however, that it is not an isolated, small-scale problem: many, many agencies lack prerequisites. One participant suggested that 50 percent of all FTA grantees may lack the prerequisites. His assertion was not disputed by the other participants.

2.3.3 Improvement Starts with Realization

These findings may seem to be sobering news for transit. In reality, they are the first critical steps toward improvement. These conclusions about prerequisites, sobering as they may be, actually greatly increase the value of the best practices presented in this report.

Simply telling agencies "what works" or "what to do" isn't the whole answer. Therefore, it is now clear that in addition to the traditional dissemination strategies for reports like this one, additional dissemination and other strategies must be pursued, and they must be accompanied by other actions focusing on establishing prerequisites. Those additional, parallel strategies—discussed further below and in Chapter 4—transcend traditional knowledge transfer activities.

It's also worth considering that rather than discouraging agencies, the somewhat somber conclusions related to prerequisites might actually invigorate agencies, lend further credence to this research, and thereby increase the chances that agencies will adopt the recommended practices that they can. How is this possible? This research study's validation of the factors that have prevented many agencies from succeeding at technology deployment may inspire those agencies to give greater consideration to the best practices recommended here than they gave to practices presented in reports that represented the practices as the "complete solution."

2.3.4 Implications for Dissemination of Study Findings

Recognition of the existence of and defining role played by prerequisites indicates that, although appropriate, traditional methods for disseminating the best practices portion of this study are insufficient. Those methods—dissemination of reports, brochures, fact sheets, and pamphlets through traditional channels; training courses; conference presentations; and so forth—must be combined with other activities. Those other activities include additional, highly targeted knowledge transfer and actions in the transportation policy arena. These activities are described in detail in Section 4.2.

2.3.5 Other Implications

As the above efforts to establish prerequisites are pursued, it may also be useful for the FTA and other funding entities to consider how they may adjust their approaches in light of "the prerequisite challenge." One such adjustment would be to give greater consideration to the presence or absence of prerequisites in awarding technology implementation grants. Agencies lacking prerequisites might, rather than receiving technology *deployment* funds, receive resources that will assist them in establishing prerequisites such as the following:

- Various peer-to-peer activities, such as scanning tours to successful agencies;
- Assistance in developing community and/or board understanding and support for transit technology investment, including help in developing and making presentations; and
- Assistance to technical staff in developing CEO/GM understanding and support for transit technology planning, implementation, and operation.

Conversely, deployment funds might be better focused on those agencies fully prepared and able to achieve success. In the short term, as the other, broader actions are pursued to propagate prerequisites, these sorts of changes in grant decisions could be the single most effective way to increase the cumulative ROI on government transit technology.

Of course, if such a strategy (focusing funding on agencies possessing the prerequisites for success) were to be pursued, it would become absolutely essential that the other strategies focused squarely on establishing prerequisites be vigorously pursued and successful. If those strategies to develop necessary prerequisites are not successful, reducing technology deployment funds for the more challenged agencies could widen the gap between successful and unsuccessful technology adopters.

2.3.6 Agencies Helping Agencies

In the preceding section, peer-to-peer activities were identified as one category of outreach and assistance recommended for agencies that lack prerequisites. One particular type of peer-to-peer strategy—one not currently common in public transportation—holds particular promise. This strategy is noteworthy not only because of its potential assistance with many of the challenges faced by transit agencies, but because it is currently underway.

UTA is leading efforts to establish the Applied Transit Technology Center. UTA describes the effort as a "collaborative effort or consortium among transit agencies to foster the application of technological innovation."[86] The Applied Transit Technology Center is expected to involve four to eight agencies and will be directed by transit agency GM. The center will be a "virtual" institution, that is, a number of its projects, programs, and activities will take place at the sites of its member agencies.

The aims of the Applied Transit Technology Center, as identified by UTA, are the following:

- Foster the application of technological innovation into the operations of American transit agencies, especially medium-size and small properties that cannot afford large technical and engineering staffs.
- Identify current problems and apply technology to solve them, rather than develop new technology.
- Adapt existing technologies to the transit environment through prototyping, testing, and piloting.
- Document and popularize current innovation being undertaken within agencies.
- Provide support for adoption of such innovations among agencies.

The reasons for developing the Applied Transit Technology Center dovetail with many of the conclusions presented in this study. That reasoning is summarized by UTA in its July 2006 Draft Proposal for the Applied Transit Technology Center:

> A special organization or institution is needed to engender collaboration among agencies for projects of common interest; provide structure in methodology, documentation and evaluation so that the results are easily and effectively transferable; and provide mechanisms and support for technology transfer acceptance, adaptation and adoption among other properties.[87]

Potential program areas for the Applied Transit Technology Center include the following:

- A "skunk works" laboratory where off-the-shelf technologies and products available in other contexts (industries) are installed and tested in a transit context. Example technologies include commercial trucking lane keeping systems and maintenance monitoring applications.
- Collection and dissemination of information, including technology transfer, from the activities of participating agencies.
- Providing a venue for a variety of peer-to-peer activities such as roundtables devoted to specific technology topics of interest to members.
- Provision of short-term, on-site technical assistance to individual agencies to accelerate deployment or troubleshoot problems, through assignment of staff or arrangement of support from other agencies.
- Providing a platform for creating consortia among transit agencies, universities, and firms and preparing joint, applied research proposals.
- Spearheading development of common specifications for technology acquisition in the absence of mature standards.
- Technically sophisticated representation of the perspectives and concerns of medium-size and small transit agencies in national and international settings.

[86] Utah Transit Authority, "DRAFT Utah Transit Authority Proposal to Create an Applied Transit Technology Center, Version 0.71" (July 12, 2006).

[87] Ibid.

CHAPTER 3

Findings on Emerging Technologies

This chapter focuses on the second of the two major objectives of this study: promoting consideration of emerging technologies for application in transit. Five "technologies to watch" are identified. These emerging technologies are those that are not currently in use by public transportation agencies, but are expected to be available to them within the next 10 years. From the research conducted for this study, it is apparent that most agencies have little if any time to devote to anticipating future technologies. The information presented here is intended to help fill that gap. Introducing these technologies here is intended to promote agencies' continued tracking of the development and applicability of these and similar technologies, ultimately improving their chances of successful adoption.

As a prelude to the discussion of future technologies, some findings are presented from the transit agency interviews. These findings characterize agencies' general perspectives on future technologies and their relative focus on them compared to existing technologies. The discussion of high-potential emerging technologies is divided into two major sections. The first identifies five "top" technologies and the second highlights a handful of other promising technologies.

3.1 Agency Perspectives on Future Technologies

From the interviews conducted for this study, it is evident that most agencies are able to devote very little attention to "emerging" or "future" technologies (those technologies not currently commercially available to transit), even though they are quite interested in these technologies. Rather, agencies seem to expend nearly all of their available resources on dealing with the challenges associated with implementing current technologies, such as electronic fare payment, and getting the most value out of their deployed technologies, such as by integrating various systems. These findings are consistent with the experience of the project team in working directly with agencies on technology projects and technology strategic planning. Agencies' focus on integration of existing systems is consistent with these major findings from the FTA report, *Advanced Public Transportation Systems: The State of the Art—Update 2006:*

> The greatest improvements in ITS will come from efforts to integrate existing technologies into cohesive state-of-the-art systems, where collectively they provide far more benefits than any one technology functioning independently.
>
> The stand-alone nature of most individual technology deployments limits the benefits that could be provided by business-oriented, enterprise-wide technology strategies.[88]

Resource constraints seemed to be the main thing preventing the interviewed agencies from focusing more on anticipating future technologies. However, for many less progressive agencies, resource constraints are not the only significant reason for the lack of attention paid to emerging technologies. The literature and the interviews and focus group conducted for this study emphasize the importance of utilizing COTS technologies when possible. This may suggest that some agencies aren't very interested in technology until they see real products they can purchase, more or less off the shelf. If this is the case, the information on emerging technologies presented here may be useful primarily to those agencies that are interested in anticipating future technologies but simply lack the resources to do so. This information may also be especially useful to consortia like the developing Applied Transit Technology Center led UTA. With their pooled resources, the Applied Transit Technology Center consortia hopes to devote much more attention to the application of the latest technology than any one transit agency can afford to devote.

[88] Hwang et al., *Advanced Public Transportation Systems.*

3.2 Emerging Technologies

3.2.1 Methodology

The methodology for researching and evaluating emerging information technologies for public transportation consisted of two major components: (1) identification of emerging technologies and (2) determination of their potential value to public transportation. The identification of emerging technologies drew upon a wide range of sources, including the following:

- Published transit and transportation reports.
- Transportation industry conference proceedings.
- Workshop materials, presentations, memoranda, and other internal public transportation agency materials.
- Related activities carried out by members of the project team, including the research and technology transfer work performed by Battelle for the National Aeronautics and Space Administration (NASA); technology projects conducted on behalf of local transit agencies; and TCRP and FTA studies, including the FTA Strategic Transit Research Plan.
- A wide range of industry and general interest technology periodicals and periodical features, including *Passenger Transport,* the annual feature stories on "10 Emerging Technologies" in MIT's *Technology Review,* and *Wired* magazine's annual "NextFest" coverage.

In addition to evaluating the extent to which the emerging technologies would impact systems and functions performed by public transportation agencies, the project team evaluated the extent to which the emerging technologies might help address major transit challenges or enable hypothesized transit advances. Both the list of challenges and list of advances were assembled primarily on the basis of the cumulative perspective and experience of the research team. In identifying challenges or problems, the research team drew heavily on their experience conducting technology-related needs studies for public transportation agencies. The "anticipated major advances" are those developments that many practitioners and technology futurists consider likely to appear in some form, at some time in the future, but which are presently undeveloped enough that the specific nature of the enabling technology and the timing of its appearance remain unclear. Identification of anticipated advances also included a facilitated focus group with members of the research team and other Battelle technology specialists and futurists. The list of challenges and list of advances are not intended to be all encompassing, but rather to capture most of the most important challenges and advances. Challenges that are not directly addressable with technology were not included, nor were advances that would require, or be the result of, any significant changes in basic public transportation paradigms, e.g., widespread privatization. Table 5

Table 5. Major challenges.

Challenge	Comments
1. ***Reduce fuel and labor costs,*** including vehicle operation, maintenance-related labor, and customer service-related labor.	Reducing costs per unit of service provided is critical for many reasons, including to survive possible threats to federal funding, to compete with other transportation alternatives (including privately operated services), and to enable more and better service.
2. Meet the needs of an ***aging and increasingly diverse (non-English speaking) population***.	The large, aging Baby Boomer generation has high expectations for travel and is more mobile than seniors of prior generations.
3. ***Increase transit mode split*** to make transit an integral and effective means to reduce traffic congestion by improving • travel time competitiveness • amenities • reliability • personal security • service integration • service planning • convenience	In most places, public transportation's share of total trips or ability to shift travel from personal automobiles is not high enough to make transit an effective tool to combat the currently very high and growing levels of urban traffic congestion. In order to attract significantly more customers, especially away from personal automobiles, agencies will need to address traditional concerns, such as travel time; "hassles" with fare payment; "confusion" among riders unfamiliar with routes, schedules, and fares; and lack of flexibility.
4. Develop and retain ***technology-savvy staff***.	Many public transportation agencies cannot currently offer competitive salaries for positions requiring skills in advanced technology and/or do not provide an organizational culture conducive to developing or retaining superior technology skills.
5. Cost-effectively ***serve suburban and rural environments***.	Lower development densities (compared to urban cores) and "many-to-many" origin and destination patterns make it very difficult to cost-effectively provide high levels of service.

Table 6. Anticipated major advances.

Advance	Comments
1. ***Automated vehicle operation and maintenance**,* including driverless operation in non-dedicated rights-of-way (e.g., in mixed traffic).	This could reduce labor costs, improve safety, reduce vehicle down-time, and potentially reduce congestion by allowing for shorter following distances. This advance includes vehicles that diagnose and repair themselves (via supporting robotic or other autonomous maintenance systems).
2. A major ***fuel/propulsion system "break-through."***	A significantly cheaper and/or cleaner alternative to today's commercially viable approaches (diesel, gasoline, natural gas, etc.) that can be widely applied.
3. ***Ubiquitous, accurate, and real-time, information on, and for, customers.***	Information *on* customers would include detailed, accurate, automatically collected information on historic travel patterns (both aggregate and for individual customers) as well as real-time location and trip itineraries. This advance includes not only the data itself but powerful, easy-to-use systems for data analysis. Information *for* customers would be personalized, essentially accessible anywhere, very accurate, real-time, and provide comprehensive modal options with cost and travel time comparisons.
4. ***Truly dynamic, seamlessly integrated (across modes, services, and agencies) service.***	Such a high degree of integration that a customer might not even know they are using multiple services. This would include the following: complete integration of service (seamless transfers); a single payment media/mechanism and transaction; and a single, comprehensive source for customer service and information. Service would be dynamic in the sense of current demand-response services but at a much larger scale and requiring no advance reservations.
5. Ubiquitous, highly effective, and highly automated ***security screening, surveillance, and response***.	This advance would feature unobtrusive, highly effective technologies that provide for a very high level of safety and security at facilities and on vehicles. This advance would effectively eliminate traditional fears or concerns on the part of many transit customers and non-customers about their personal safety and security.

presents the list of challenges and Table 6 presents the anticipated major advances.

An additional key criterion in evaluating emerging technologies was that they not be currently in use, even on a demonstration basis, by public transportation agencies (one exception was made to this criterion, as described in Section 3.2.2). On the other end of the development timeline, technologies unlikely to be commercially viable within 10 years were eliminated from consideration.

3.2.2 Five High-Potential Technologies to Watch

From among the dozens of technologies considered, five technologies were selected as having the greatest potential for public transportation. These high-potential technologies are described in the sections that follow. Each description includes an explanation of what the technology is and how the technology relates to the major transit challenges and anticipated transit advances identified by the research team (listed in Tables 5 and 6, respectively).

3.2.2.1 Large-Scale Adoption of Hybrid-Electric Transit Buses

Explanation of hybrid-electric transit buses. For this technology, an exception was made to the "no deployed technologies" selection criterion described in the methodology (Section 3.2.1)—about 700 hybrid-electric buses are now in operation in North America, including in New York City and King County, Washington.[89]

[89] R. Barnitt and K. Chandler, *New York City Transit (NYCT) Hybrid (125 Order) and CNG Transit Buses, Final Evaluation Results,* NREL/TP-540-40125 (Washington, D.C.: U.S. Department of Energy, November 2006); King County Department of Transportation, "News from King County Transportation," press release (Seattle, WA: May 27, 2004), www.metrokc.gov/kcdot/news/2004/nr040527_hybrids.htm.

The exception was made because of the very dramatic impact that *widespread adoption* of this technology is expected to have on most bus operators. Proliferation of this technology will impact most transit agencies at least as much as the other truly "new" technologies described here. Also, there are a number of emerging energy storage technologies that will benefit and hasten hybrid adoption. Finally, the extensive on-board computer systems associated with hybrids create great potential for more extensive on-board monitoring than is possible with diesel or compressed natural gas vehicles.

In the last several years, high fuel costs, concern about the dependence on foreign oil, and concern about air quality have heightened interest in alternative fuel sources and propulsion systems for public transportation. There is considerable disagreement among experts regarding which fuel/propulsion technologies will become widely adopted and, especially, *when* they will become adopted. However, it is the opinion of many experts that within 10 years, hybrid-electric heavy-duty transit vehicles are the most likely fuel/propulsion technology to significantly penetrate and benefit public transportation. A few areas with truly extreme air quality concerns, namely in California, continue to move forward rapidly in the development and demonstration of fuel cell buses.[90] However, in areas with less dire air quality conditions, the high cost of fuel cells and major hydrogen production challenges are likely to delay any significant penetration of public transportation by fuel cells to beyond the 10-year horizon, if ever. According to one FTA report:

> fuel cells are seen as the long-term goal by many . . . although there are some in the transit world who see fuel cells as unlikely to ever be commercially viable for transit. For those who see them as the long-term solution for vehicle propulsion, the time-frame for commercial products is seen as 10 years at a minimum, with perhaps commercial fuel cells not being available for another 20 years.[91]

And another source has commented that

> fuel cells, while a promising technology, could take more than 50 years to have a significant impact on gasoline consumption . . . The estimates assume that competitive fuel cells will be available within 15 years, an achievement that will require improvements, for example, in hydrogen storage and production and fuel cell costs.[92]

The prognosis for transit vehicles fueled directly by hydrogen (as opposed to hydrogen fuel cells) is even less optimistic, as there are serious doubts about whether hydrogen will ever be a feasible fuel for vehicles.[93]

The feasibility and benefits of hybrid-electric buses, on the other hand, have been well established in field deployments, and these vehicles have moved beyond demonstration into commercial production.[94] Hybrid-electrics do not require a new fueling infrastructure; demonstrate improved acceleration, reduced noise and vibration, and less brake wear and maintenance; are comparable to or better than compressed natural gas and diesel buses in the output of regulated emissions; and are demonstrating 10 percent to 50 percent better fuel economy. There are a number of major challenges associated with hybrid-electrics, however. These include high capital costs for the vehicles (60 percent to 80 percent higher than comparable diesel buses) and the high cost and uncertain lifespan of batteries.

There are several emerging technologies in the area of energy storage (e.g., batteries) that hold promise for addressing some of the battery-related concerns with hybrid-electric transit buses and thus could increase the rate of hybrid-electric transit bus adoption. Battery advances include several improvements on conventional lithium ion batteries that will reduce cost, increase electrical current, and improve safety. One such advance is the lithium iron phosphate battery, recently debuted in a line of power tools and expected to have application to hybrid-electric vehicles. The lithium iron phosphate battery would be one-fifth the weight of today's hybrid vehicle batteries; could withstand 10 times more recharging; could be recharged much more quickly; and, being very chemically stable, would be much less likely to leak or explode.[95] These batteries also hold the potential for making "plug-in" hybrid vehicles—vehicles with batteries that can be recharged by plugging them into a wall socket—much more feasible.[96] Another promising improvement to lithium ion batteries uses lithium, nickel, and manganese and provides much greater

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[90] K. Chandler and L. Eudy, *Santa Clara Valley Transportation Authority and San Mateo County Transit District, Fuel Cell Transit Buses: Evaluation Results,* NREL/TP-560-40615 (Washington, D.C.: U.S. Department of Energy, November 2006); WestStart-CALSTART, "FTA Provides Funding for Advanced Fuel Cell Bus Projects to CALSTART," press release (October 12, 2006), www.calstart.org/aboutus/nl_detail.php?id=87.

[91] L. Callaghan and S. Lynch, *Analysis of Electric Drive Technologies for Transit Applications: Battery-Electric, Hybrid-Electric, and Fuel Cells,* FTA-MA-26-7100-05.1, prepared by the Northeast Advanced Vehicle Consortium for the FTA, U.S. DOT (Washington, D.C.: August 2005), www.navc.org/Electric_Drive_Bus_Analysis.pdf.

[92] K. Bullis, "Hydrogen Reality Check," *Technology Review* (May 5, 2005), www.technologyreview.com/Energy/16777/.

[93] D. Appell, "Hydrogen Hype," *Technology Review* (October 12, 2004), www.trblogs.com/blog/post.aspx?bid=293&bpid=15343; D. Talbot, "BMW's Hydrogen Hopes," *Technology Review* (September 22, 2006), www.technologyreview.com/read_article.aspx?ch=specialsections&sc=transportation&id=17526&a=f.

[94] Chandler and Eudy, *Santa Clara Valley Transportation Authority.*

[95] K. Bullis, "More Powerful Batteries," *Technology Review* (November 21, 2005), www.technologyreview.com/read_article.aspx?id=15913&ch=nanotech.

[96] K. Bullis, "Making Electric Vehicles Practical," *Technology Review* (November 29, 2006), www.technologyreview.com/Nanotech/17837/.

storage capacity.[97] Ultracapacitors or supercapacitors are emerging alternatives to batteries that have the potential to be 10 times more powerful than batteries and actually outlive a vehicle. A recent breakthrough is the use of carbon nanotubes, a nanotechnology (see Section 3.2.2.2) that increases the surface area of electrodes and thereby the ability to store energy.[98]

Finally, in addition to the emerging energy storage technologies, there are aspects of hybrid-electric bus technology that increase the potential of additional technology applications. Specifically, the complex and extensive on-board computer monitoring system required in hybrids creates opportunities to do much more extensive on-board monitoring than is now possible. A current constraint on such monitoring is the lack of a single, comprehensive on-board monitoring system. Most current vehicle component monitoring systems have their own configuration and cannot easily be integrated.

Relationship to major transit challenges and anticipated transit advances. The expected major shift to hybrid-electric buses, spurred by continuing advances in energy storage technologies, obviously relates most closely to the "major fuel/propulsion system 'break-through' " major advance listed in Table 6. In terms of addressing transit challenges listed in Table 5, this technology fits most closely with the "reduce fuel and labor costs" challenge, although cost savings in fuel (due to greater fuel economy) might very well be offset by higher vehicle purchase and maintenance costs.

3.2.2.2 Nanotechnology

Explanation of nanotechnology. Nanotechnology is an area of applied science and technology that covers a wide range of topics and entails controlling and exploiting the structure of matter on a scale below 100 nanometers. There are a number of nanoelectronic applications, ranging from those that make solar power cost-effective to those that will greatly increase the power and reduce the size and power consumption of microprocessors. The potential benefits to transit, especially of the more powerful microprocessors, are significant and cover a wide range of applications, including office computing, sensing, and two-way exchange of information with customers.

Many of the potential advances associated with nanotechnology utilize carbon nanotubes, cylindrical arrays of individual carbon molecules that are very strong and exceptionally good conductors of heat and electricity. For example, in theory, metallic nanotubes (carbon nanotubes are either metallic or semiconductors) can have an electrical current density more than 1,000 times greater than metals such as silver and copper. There have been breakthroughs in both applications for carbon nanotube technology and processes for manufacturing them. An example of an emerging application is quantum wires, wires spun from carbon nanotubes that could carry electricity farther and more efficiently and transform the electrical power grid.[99] Such an advance could reduce the cost of electricity for transit.

Another carbon nanotube application is universal memory. Universal memory is an ultradense, low-power data storage medium that encodes bits using the physical orientation of nanoscale structures rather than using an electric charge on a circuit element, as with conventional electronic memory. This technology could eventually allow a much greater amount of data to be stored on computers and mobile devices.[100] For example, experts estimate that within 20 years the contents of all the DVDs ever made could be stored on a laptop computer. Such dramatic computer memory advances will impact a wide range of transit computing applications: scheduling, dispatch, customer information, on-board diagnostics and computerized maintenance systems, and still-emerging transit applications of robotic and virtual reality technologies.

Emerging technologies that are facilitating the manufacture of carbon nanotubes, thus speeding the benefits of nanotube technology applications, include an etching process that can be integrated with the methods used to carve out traditional silicon-based computer chips.[101]

There are a number of nanotechnology developments that hold the potential to dramatically increase the cost-effectiveness of solar power, providing transit a non-polluting and renewable energy alternative. For example, Nanosolar, a startup in Palo Alto, California, has developed a way to mass produce thin-film solar cells using an affordable printing technology similar to the kind used to print newspapers.[102] Other researchers have developed "quantum dots" from heated silicon that can be used to make ultra-efficient solar cells.[103] A sign of the increasing viability of solar power is

[97] K. Bullis, "Battery Breakthrough," *Technology Review* (February 21, 2006), www.technologyreview.com/printer_friendly_article.aspx?id=16384.

[98] P. Fairley, "Ultrahybrid," *Technology Review* (September 2001), www.technologyreview.com/printer_friendly_article.aspx?id=12558; K. Bullis, "The Ultra Battery," *Technology Review* (February 13, 2006), www.technologyreview.com/printer_friendly_article.aspx?id=16326.

[99] E. Jonietz, "10 Emerging Technologies Special Report: Quantum Wires," *Technology Review* (May 2005), www.technologyreview.com/read_article.aspx?ch=infotech&sc=&id=14407&pg=2.

[100] T. Huang, "10 Emerging Technologies Special Report: Universal Memory," *Technology Review* (May 2005), www.technologyreview.com/read_article.aspx?ch=infotech&sc=&id=14407&pg=6.

[101] P. Patel-Predd, "A Step Closer to Nanotube Computers," *Technology Review* (November 2006), www.technologyreview.com/printer_friendly_article.aspx?id=17785.

[102] K. Bullis, "Large-Scale, Cheap Solar Electricity," *Technology Review* (June 23, 2006), www.technologyreview.com/printer_friendly_article.aspx?id=17025.

[103] K. Greene, "More Efficient Solar Cells," *Technology Review* (October 26, 2006), www.technologyreview.com/printer_friendly_article.aspx?id=17664.

Google's conversion of its headquarters to run partly on solar power.[104]

Relationship to major transit challenges and anticipated transit advances. Nanotechnology is having, and will continue to have, dramatic impacts throughout society and will almost certainly play an important part in nearly all of the anticipated major transit advances. These advances include increasing automation of vehicle operations, ubiquitous information exchange with customers, seamless integration of services, and ubiquitous security screening and surveillance. Further, nanotechnology will likely help agencies meet the needs of older and non-English speaking customers and promote transit ridership by improving convenience and security.

3.2.2.3 Mechatronics

Explanation of mechatronics. Mechatronics entails the integration of traditional mechanical systems with electronic components and intelligent software control. The term refers to the synergy achieved through the integration of mechanical, electronic, and information technologies. Examples of this integration in vehicle brakes include replacing hydraulic cylinders with electromechanical actuators, replacing brake fluid lines with wires, and using software that will mediate between the driver's foot and the action that slows the vehicle. Increasingly, researchers are coming to believe that mechatronic systems can be made much safer and effective than traditional mechanical systems. A large part of the safety benefit derives from the ability to build in fault diagnoses and fault tolerance. Essentially, linking mechanical systems of the type found throughout transit vehicles with electronic systems unlocks the potential to monitor and optimize the performance of the systems using sophisticated computers.

The potential benefit to public transportation of the continued evolution of mechatronic systems is significant. Such systems could improve fuel economy, performance, safety, and maintenance. Mechatronics also plays a central role in a wide range of vehicle safety systems that link electronic sensor data with actuation of mechanical systems like steering and brakes. Thus, mechatronics are critical in the evolution toward a heavily computer-assisted, or even autonomous, transit bus.

An example of a recent innovation in mechatronics is the development of software by a German university that identifies and corrects for flaws in real time, thereby improving the performance of mechatronic braking systems.[105] The software tracks data from three sensors: one that detects the flow of electrical current to the brake actuator, a second that tracks the actuator's position, and a third that measures its clamping force. The software analyzes those inputs to detect faults and alert drivers to the need for service.

Relationship to major transit challenges and anticipated transit advances. In regard to anticipated major transit advances, the greatest impact of mechatronics is likely to be in enabling increasing levels of automation in vehicle operation. Among the transit problems, mechatronics' greatest potential may lie in its ability to minimize operating costs by improving maintenance effectiveness.

3.2.2.4 Speech Recognition and Language Translation

Explanation of speech recognition and language translation. Speech recognition and automated language translation have been around for some time but the problem has been that they often do not work very well. In the case of speech recognition, systems like airline and banking IVR systems perform very well only when there are a limited number of potential user inputs. The poor performance of automated language translators is apparent to anyone with much experience with online translators like AltaVista's Babel Fish (http://babelfish.altavista.com/tr). Translating the phrase "Which bus should I take to get to the Downtown Transit Center and when will it arrive?" from English to Korean and then back to English yields "Me other Oh! under it boils which bus it gets in the feeling mobile center and to respect it time it arrives to respect?" When voice recognition is combined with language translation, the challenges are compounded.

There are a number of advances underway in speech recognition and language translation that are expected to significantly improve performance. Fast, highly accurate speech recognition and language translation could revolutionize many aspects of public transportation operations, including the way transit passengers interact with customer information systems to perform complex operations like itinerary planning. Advances could also improve the interfaces between transit personnel and the many computerized systems they interact with both on board and in the office. Improvements in language translation could greatly enhance transit's ability to provide quality service to the increasing number of customers who have limited English skills.

One example of recent advances in voice activation is the research that Nokia and MIT are conducting to teach cell phones to take commands in natural language, that is, teaching cell phones to understand and respond to written com-

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[104] Associated Press, "Google to Convert HQ to Solar Power," *Boston.com* (October 16, 2006), www.boston.com/news/science/articles/2006/10/16/google_to_convert_hq_to_solar_power/.

[105] "10 Emerging Technologies That Will Change the World: Mechatronics," *Technology Review* (February 2003), www.technologyreview.com/printer_friendly_article.aspx?id=13060.

mands typed in English.[106] Nokia's natural language technology utilizes a software system developed at MIT that interprets human questions and finds answers using websites. The software is unique because it *interprets* human language rather than looking for keywords. The key to the interpretation is the breakdown of English sentences into components: objects, properties, and values. When perfected, the Nokia-MIT system will vastly simplify user interfaces with handheld devices, like cell phones, allowing users to access many functions and make complicated requests without wading through layers of menus. The language commands will also enable people to have their various technologies communicate with other devices. For instance, an individual could tell his/her phone to retrieve route and schedule information from a transit website, and the phone would automatically coordinate the information transfer.

Google is also contributing to the advances in voice activation and speech recognition.[107] Google was recently granted a patent for a voice-enabled search engine and has hired several well-known speech-recognition specialists, developments that suggest that a new product is in development. Google's voice search patent takes a handful of word and phrase possibilities and runs them through the powerful Google search engines. Rather than relying on perfect voice recognition accuracy, the voice-enabled search engine relies on Google's powerful search algorithm to focus on the most likely possibilities.

Google is also developing techniques for translating languages and has earned high marks for accuracy in National Institute of Standards and Technology challenges.[108] The Google approach isolates short sequences of words and then searches current translations to see how those sequences have been translated before. The system finds several different translations and identifies the most probable translation—again, leveraging the powerful statistical approach that drives Google's web search engine.

The Defense Advanced Research Projects Agency (DARPA) is leading a major effort to improve machine language translation that incorporates speech recognition, translation, and meaning summarization.[109] DARPA's aim is to create a real-time translation software called GALE, for Global Autonomous Language Exploitation. DARPA has engaged three teams, or "contestants," to work separately on the project, one of which is IBM. The intent is for the translation system to listen to TV broadcasts or phone conversations and read websites in Arabic and Chinese, translate them into English, and summarize the key elements.

Relationship to major transit challenges and anticipated transit advances. Anticipated breakthroughs in speech recognition and language translation would most directly impact the anticipated major transit advances associated with ubiquitous two-way information exchange with customers and seamlessly integrated, dynamic transit services. In terms of transit problems and challenges, these technologies hold the greatest potential in the areas of meeting the needs of aging and non-English speaking customers and in reducing customer service labor costs. To a somewhat lesser extent, these technologies would contribute to improvements in convenience that could translate into increases ridership/mode split.

3.2.2.5 Pervasive Wireless and Cognitive Radio

Explanation of pervasive wireless and cognitive radio. Pervasive wireless describes a future condition when a wide range of mobile, radio-equipped devices—cell phones, computers, and various sensors—will be able to form ad hoc communications networks.[110] Cognitive radio is one of the methods for doing so. Cognitive radio and the broader promise of a pervasive wireless network would revolutionize transit agencies' ability to communicate with their customers, with their various mobile and fixed assets, and with the assets of other transit agencies.

Among the advances supporting the development of pervasive wireless is the development of a radio test grid by Rutgers University. The grid allows researchers to evaluate alternative methods for forming the ad hoc networks that enable pervasive wireless communications. The Rutgers radio grid is the first large-scale shared research facility for studying multiple wireless devices and network technologies. One of the primary challenges to be overcome is that different devices communicate using different radio standards: RFID tags use one set of standards, cell phones another, and Wi-Fi devices yet another standard. Standardization of protocols, enabled by advances such as the Rutgers radio test grid, is a key step in the ultimate realization of pervasive wireless.

Cognitive radio is a way to maximize the limited bandwidth—radio spectrum—available for wireless data communication, an increasingly necessary strategy given the rapidly expanding number of wireless devices in use by transit customers and transit agencies. The main problem, according

[106] K. Bourzac, "Nokia Phones Go to Natural Language Class," *Technology Review* (April 27, 2006), www.technologyreview.com/printer_friendly_article.aspx?id=16745.

[107] K. Green, "The Search for Voice Activation," *Technology Review* (April 21, 2006), www.technologyreview.com/printer_friendly_article.aspx?id=16725.

[108] S. Ornes, "Not Lost in Translation," *Technology Review* (November 16, 2006), www.technologyreview.com/printer_friendly_article.aspx?id=17793.

[109] Associated Press, "Building the Government's Translation Machine, 1 Year at a Time." *nwi.com* (November 4, 2006), http://nwitimes.com/articles/2006/11/05/business/business/0335e24cc9e7e0a48625721b0074b699.txt.

[110] N. Savage, "10 Emerging Technologies Special Report: Pervasive Wireless," *Technology Review* (March/April 2006), www.technologyreview.com/printer_friendly_article.aspx?id=16476.

to researchers, is not the lack of bandwidth, but the way the spectrum is used.[111] Spectrum is allocated by the Federal Communications Commission (FCC) into frequency ranges corresponding to various types of devices. At any given time, at any given location, a large percentage of a given frequency may be available even though the frequency range is reserved. Cognitive radios figure out which frequencies are available and pick one to transmit and receive data, taking advantage of locally available bandwidth that may fall outside the range officially reserved for the device.

Researchers at the University of California, Santa Barbara, are trying to improve cognitive radio by teaching the devices to negotiate with other devices in their vicinity. In their scheme, the FCC-designated owner of the spectrum gets priority, but other devices can divide up the unused spectrum among themselves. Because negotiation between the devices itself uses up spectrum, the researchers are using rules from "game theory"—a type of mathematical modeling used to find optimal solutions—and have designed software that makes the devices follow the rules. Rather than telling a neighboring device what it is doing, each radio observes what its neighbors are doing and makes its own decisions.

Cognitive radios are already becoming commercial. Intel has plans to build reconfigurable chips that will use software to analyze their environments and select the best protocols and frequencies for data transmission. Nokia is also working to incorporate cognitive radio capabilities in their cell phones; they say that these capabilities would make it possible to transfer a movie from your PC to your phone in 2 seconds.[112] Nokia also recently announced a new short-range wireless technology called Wibree, which is similar to Bluetooth, but consumes less power. Wibree would enable a phone to act like a node in wireless sensor networks, collecting information such as location, aggregating data from nearby sensors, processing it, and sending it to other sensors and phones via Wibree or Wi-Fi networks.

Relationship to major transit challenges and anticipated transit advances. Cognitive radio and its contribution to pervasive wireless networks have the potential to enable several of the anticipated major transit advances: ubiquitous, real-time, two-way information exchange with customers; dynamic, seamlessly integrated service; and ubiquitous, highly automated security screening, surveillance, and response. In terms of major challenges faced by transit, these technologies will likely contribute to ridership and mode split increases by improving convenience, service integration, and personal security.

[111] N. Savage, "10 Emerging Technologies Special Report: Cognitive Radio," *Technology Review* (March/April 2006), www.technologyreview.com/read_article.aspx?ch=specialsections&sc=emergingtech&id=16471.
[112] Ibid.

3.2.3 Other Promising Emerging Technologies

The five technologies identified in Section 3.2.2 are considered to have particular potential because they either impact many areas of functionality important to transit—such as nanotechnology (sensing, communications, and data processing)—or because they are expected to have a particularly significant impact. There are, however, many additional emerging technologies that, given the inherent unpredictability of the future and the challenges of predicting the timing and nature of technology impacts, may ultimately be as important to transit. A number of these additional technologies are highlighted in this section.

3.2.3.1 Flexible Displays and Microprocessors

Transit travelers have expressed an interest in viewing more information with better displays on their PDAs. Xerox and E-Ink are developing electronic paper technology, which will instantly display information on various tablet personal computer-like surfaces in the form of text and graphics. It is expected that this technology will be available in the next 5 years. People currently dependent on PDA screen displays can use electronic papers for larger displays of real-time information provided by transit agencies.[113] A Japanese enterprise, Fujitsu, has already developed bendable color electronic paper.[114]

Related advances include "stretchable silicon," a practice that utilizes ultra-thin strips of silicon—only a few hundred nanometers thick—to contain high-performance conformable circuits. This advance will mean that not only can passive displays be made flexible (e.g., electronic paper), but computer chips themselves can be integrated into fabric-like materials that could conform to pliable surfaces.[115] This could mean, for example, that communications and sensors, including sensors for explosives and other security applications, could be integrated into the seat coverings in a transit vehicle.

3.2.3.2 Improved Vehicle Navigation

There are a number of emerging technologies that will address current accuracy and signal loss problems with GPSs for transit. For example, pseudo-satellites, often called pseudo-

[113] L. A. Ragaza, "Technologies to Watch: Electronic Paper," *PCMag.com* (September 4, 2001), www.pcmag.com/article2/0,1759,32904,00.asp.
[114] Fujitsu, "Fujitsu Develops World's First Film Substrate-Based Bendable Color Electronic Paper Featuring Image Memory Function," press release, www.fujitsu.com/global/news/pr/archives/month/2005/20050713-01.html.
[115] K. Greene, "10 Emerging Technologies Special Report: Stretchable Silicon." *Technology Review* (March/April 2006), http://www.technologyreview.com/article/16477/.

lites, can help in overcoming such navigation problems.[116] Pseudolites are ground-based transmitters of GPS-like signals and can help in navigation by either complementing GPS (compensating for the GPS signal loss) or by completely replacing the GPS satellite constellation. Alternate research in the field of robotics has identified the possibility of using neural network-based tools for navigation. Neural network algorithms determine a vehicle position and angular orientation (direction) of the vehicle with the help of on-board range sensors. Range sensors measure the distance between an object and the sensor. This navigation technique does not need any external reflector, active beacon, or buried wire, and the system automatically maintains calibration as it moves through the environment.[117]

Another advance from the field of robotics that will help fill GPS signal loss gaps utilizes advanced processing of stereo video images.[118] This advance, not yet published, is being led by researchers at Sarnoff, in Princeton, New Jersey. The technology provides excellent accuracy—to within 1 meter after ½-kilometer of moving through so-called GPS-denied environments. The approach, which uses four small cameras, is believed to represent a five-fold increase in accuracy. Solving the problem of areas of GPS signal loss will facilitate the application of GPS to safety-sensitive applications like lane keeping. A related development in robotic vision that could enable greater use of robotics in vehicle and facility maintenance is called selective-attention modeling. In this technique, robots are programmed to try to evaluate scenes, as humans are believed to do.[119] In this approach, robots focus on anomalous sights in basically the same way a human brain does when scanning a "what's wrong with this picture?" type of puzzle.

3.2.3.3 Artificial Intelligence

Artificial intelligence (AI)-based technologies, such as machine learning methods that include neural networks and fuzzy logic, promise benefits for transit. These technologies will be very helpful in processing noisy ITS data (both nonimagery and imagery) and will help in data analysis and decision making.[120] Bayesian Machine Learning, a probabilistic machine learning approach that deduces likely relationships from a large body of data, could also have applications in transit.[121] For example, it could be used to support automation of the personalization of passenger information by identifying patterns and preferences reflected in past inquiries or travel itineraries.

3.2.3.4 Silicon Photonics

Current IT infrastructure provides high-speed Internet using a fiber-optic cable network, but the data transfer inside computer elements is still slow due to copper wire that is used within circuits. Faster data communication in and between computer chips will be achieved by evolution of new technologies such as silicon photonics.[122] This technology will offer optical communications between silicon chips instead of the current communication through electrical signals. Optical communication will be possible by enabling silicon to emit photons. Although photon-based interconnects are expected to be available in about 5 years, light-wave communication between components on the same chip will be possible only in the long term.

Another emerging technology that will increase the speed of communications is microfluidic optical fibers. These employ tiny droplets of fluid inside fiber-optic channels to improve data flow, speeding transmission and improving reliability.[123] Fibers are bored with microscopic channels; pumping in various tiny amounts of fluids can change the properties of the fiber, allowing for corrections to error-causing distortions and directing data flows more efficiently. This alternative is cheaper than adding more bandwidth and would allow transit agencies to get the most out of their fiber investments.

3.2.3.5 Data Security

Increased reliance on digital systems and wireless communications will make data security increasingly important. A single password hack can corrupt an entire system. For example, on-board Wi-Fi Internet capability needs to be secured (better than the currently available Wired Equivalent Privacy [WEP]–based encryption) so that users cannot get into the wireless local area network (LAN) of the agency. Quantum cryptography, developed at IBM's T. J. Watson Research Center, can help with much better encryption. Moreover, IBM, with the help of the University of

[116] Y. Toba, M. Saitou, N. Yanagihara, and M. Watanabe, "Basic Verification Concerning High Precision Positioning Detection Using Pseudolite," *Proceedings of the 9th ITS World Congress* (Washington, D.C.: ITS America, 2002).

[117] www.nttc.edu/techmart.

[118] T. Mashberg, "GPS That Never Fails," *Technology Review* (November 30, 2006), www.technologyreview.com/Infotech/17841/?a=f.

[119] J. C. Diop, "Robotic Vision," *Technology Review* (October 2002), www.technologyreview.com/Infotech/12976/?a=f.

[120] Z Solutions, Inc., "A Manager's Guide to Neural Networks," white paper (Atlanta, GA: 2004), www.zsolutions.com/pdfs/amanager.pdf.

[121] D. Koller, "10 Emerging Technologies That Will Change Your World: Bayesian Machine Learning," *Technology Review* (February 2004), www.technologyreview.com/Infotech/13438/page5/.

[122] N. Savage, "10 Emerging Technologies: Silicon Photonics," *Technology Review* (May 2005), www.technologyreview.com/read_article.aspx?ch=infotech&sc=&id=14407&pg=3.

[123] J. Rogers, "10 Emerging Technologies That Will Change Your World: Microfluidic Optical Fiber," *Technology Review* (February 2004), www.technologyreview.com/read_article.aspx?ch=infotech&sc=&id=13438&pg=10.

New Mexico, is also developing artificial immunology to protect computers from viruses. This concept will model immune systems based on human biology. These technologies should be available by 2020.[124]

3.2.3.6 Terahertz Radiation

Terahertz waves could improve the speed of wireless communications and security screening. Terahertz radiation—T-rays—operate in the deep-infrared region just before wavelengths stretch into microwaves. T-rays are able to easily penetrate many common materials without the medical risks of X-rays. They promise to transform fields like airport and transit security, revealing not only the shape but also the composition of hidden objects, from explosives to cancers.[125] A very recent breakthrough will increase the ability to control terahertz waves, making for clearer images and faster wireless communications.[126]

[124] S. Carroll, "Technologies to Watch: Information Security," *PCMAG.COM* (September 4, 2001), www.pcmag.com/article2/0,1759,32904,00.asp.

[125] D. Arnone, "10 Emerging Technologies That Will Change Your World: T-Rays." *Technology Review* (February 2004), www.technologyreview.com/Infotech/13438/page6.

[126] D. Graham-Rowe, "Taming the Terahertz," *Technology Review* (November 30, 2006).

CHAPTER 4

Conclusions

This chapter summarizes the major conclusions and recommendations of this study. The conclusions are organized into two major sections. The first section presents conclusions related to improving transit agency implementation and operation of advanced technologies, including anticipation of high-potential emerging technologies. The second section presents recommendations for disseminating the results of this study and for associated follow-up actions necessary to ensure that the recommended agency practices generate their full benefit.

4.1 Improving Technology Implementations

Six major conclusions of this study (not listed in order of importance) are the following:

1. **There is an opportunity to move past the struggles in deploying technology that have limited technology benefits for the transit industry.** While advanced technology has been applied to public transit for more than 20 years, it has been done with *varying degrees of success.* Over the same period of time, several guidance documents have provided information regarding the best practices associated with technology deployment. Nonetheless, agencies continue to have difficulties with technology deployment. These difficulties are not so much with the technology itself, as they are with associated deployment issues (e.g., organizational change). As a result of these continuing difficulties, transit agencies generally are not getting the full benefits of deployed technologies.
2. **Commitment, vision, organizational change, a champion, and a realistic business case are necessities for successful deployment of technology.** Those agencies that have been successful in deploying technology have made a *significant commitment* to the technology, but perhaps more importantly, to these four requirements:
   - Establishing and communicating a *vision* for the organization that describes how technology will help achieve the organization's goals and objectives. Agency leadership (CEO/GM and board) should contribute to the development of the vision and should thoroughly understand and support it. That support should include policies and resource allocations necessary to realize the vision. Development of the vision should also meaningfully involve the range of agency stakeholders (e.g., riders/users, taxpayers, policy makers, employees, and media) and adequately reflect their needs and perspectives. Accompanying the vision should be a clear, sequential *plan* for achieving the vision through specific investments and supporting actions.
   - Having a *champion* throughout the planning, procurement, and deployment of the technology who is passionate about the vision, can articulate the vision in common language, and can discuss the vision anywhere at any time.
   - Recognizing the need for and embracing *organizational change,* including understanding the stages of change, being proactive in addressing and mitigating the reactions of staff at each stage, empowering staff, and utilizing outside assistance when necessary.
   - Understanding the long-term *business case* for, and implications of, procuring and operating the technology. This should include a realistic cost-benefit or ROI analysis, even if it is only qualitative, and a formal, post-deployment evaluation of observed benefits.

   Not only are these elements necessary for successful technology implementation, some of them, such as a having a vision and a champion, describe fundamental conditions, *prerequisites,* which must be present before an agency can follow many recommended best practices.
3. **Transit needs to follow the example of successful private-sector technology adopters by using more rigorous planning and implementation processes.** Using EAP and

SE is essential for successfully deploying technology systems. Until the U.S. transit industry fully embraces these important planning and design techniques, technology performance will remain far below its potential. Transit can follow the examples provided by other industries that utilize EAP and SE and draw analogies to the transit business as they strive for success. Utilizing these techniques will require more funding than is usually required for technology deployment, so efforts to obtain funding for technology will need to be more innovative.

4. **An agency must realistically assess its capability to make a technology deployment fully successful.** The decision to pursue technology deployment should take into consideration whether the aforementioned prerequisites—those important pre-existing conditions, attributes, and capabilities that are necessary for an agency to effectively apply the practices recommended in this report—are in place. Too many times, external factors, such as politics and board of directors' interests, have forced an agency to rush into a project without having the appropriate prerequisites and resources. An agency must be realistic about what it can and cannot do regarding technology planning, design, procurement, deployment, and ongoing operation and maintenance. If an agency determines that its internal capabilities are lacking, it can make meaningful progress by first establishing its "basic skills" for successful technology implementation.
5. **Emerging technologies have the potential to help address the important issues that are facing transit in the next 10 to 20 years.** These important issues include the needs of an aging society and rising fuel prices. However, agencies will need to understand the effects of new technologies on their organizations before planning how they will address future issues. Technologies do not generate benefits unless an agency integrates the technology into its operations and makes necessary changes to the organization to fully embrace and utilize the technology. This study revealed that many agencies that have adopted technology systems expend available resources on maintaining, updating, and integrating those systems and lack the resources necessary to systematically scan emerging technologies. Thus, dissemination of information regarding new technologies, specifically regarding the benefits that can be derived from deploying them, will be a necessity and must be done in a way that minimizes agency research efforts. Finally, given the great potential of emerging technologies, it is vital that the transit industry strive to better anticipate and more quickly adopt these technologies. In focusing on agencies' many challenges with current technologies, the significance of emerging technologies cannot be ignored.
6. **Adoption of the recommendations of this study is dependent on more aggressive and effective dissemination approaches than have been used in the past.** Although this study places far greater emphasis on some state-of-the-art and essential practices than has been done in the past, some of the practices recommended here have been identified previously. In order for the findings of this study to have their intended impact—stimulating significant improvements in transit technology implementation—an enhanced approach to dissemination is required. Recommendations for dissemination are described in Section 4.2.

4.2 Disseminating Study Findings

A three-pronged model is recommended for the dissemination of the findings of this study. The three prongs of the dissemination/follow-up model are the following:

1. Conduct traditional TCRP knowledge transfer;
2. Incorporate several new or enhanced knowledge transfer methods; and
3. Carry out, in parallel, several additional activities that focus on impacting transit policy rather than knowledge transfer per se.

Each of the three prongs of the dissemination/follow-up model are described below.

4.2.1 Traditional TCRP Knowledge Transfer

The first prong of the dissemination model, traditional TCRP knowledge transfer, is useful and appropriate, but will need to be supplemented with other dissemination methods and activities to fully meet the challenges identified by this study. Traditional TCRP knowledge transfer activities include the following:

- Publish this report as well as brochures, fact sheets, pamphlets, or similar material with condensed versions of the study results.
- Incorporate the findings of this report into existing training courses and develop new courses, if necessary, to address all the needs identified in this study (e.g., SE, EAP and Change Management).
- Present the results of this report at conferences and meetings, including the TRB Annual Meeting; the ITS America Annual Conference; and several APTA meetings and conferences, including the Annual Meeting, the Bus and Paratransit Conference, the Bus Rapid Transit Conference, the Transit Board Members Seminar and Board Support Employee Development Workshop, the TransITECH Conference, and the Transit CEOs Seminar (formerly General Managers Seminar).
- Incorporate the findings of this report into other planned workshops and forums and consider new workshops or forums dedicated to the findings of this report.

4.2.2 New/Enhanced Knowledge Transfer

The second prong of the strategy for dissemination of results and other follow-up actions in part represents enhancements or refinements in the way some traditional activities are carried out (see Section 4.2.1), and in part will represent new activities incorporating new methods. The overall objective of this second prong is to take steps to enhance the penetration and ultimate value of the study findings among the practitioner community. This objective responds to two major challenges.

The first challenge is that most practitioners face an enormously crowded and somewhat chaotic information environment and are, essentially, in "information overload." With tools like the Internet, the rapid proliferation of industry and topic-specific subscription e-mail newsletters, and the new RSS (Really Simple Syndication) feeds, the problem for most practitioners is no longer an absence of information per se, but inadequate time to scan it, identify what's useful, and then remember they have it. Simply publishing a report and making a few conference presentations may have been a sufficient way to disseminate findings 10 years ago, but a different strategy is needed now.

The other challenge is that past attempts to address many of the same problems this study addresses have been inadequate, despite making good information available to the transit community. As elaborated in the discussion of prerequisites, a main reason for that prior failure is that the recommended practices aren't easy to put into practice for most agencies. Agencies with organizational climates that do not fully support technology investment are not places where an IT, planning, or operations manager can simply start using EAP and SE techniques. Likewise, agencies that are profoundly resource-challenged simply cannot afford to use many of those costly best practices even when the up-front investment is returned many times over.

The way that these challenges must be addressed is to more effectively target and craft the dissemination of study findings. Effective dissemination of study findings entails using the 3 Ms: the right (uniquely responsive and therefore effective) message, messenger, and mechanisms.

The *message* will be unique and responsive if it stresses that (1) agencies must understand and utilize techniques like SE in a truly meaningful way (not in a superficial way simply to comply with the FTA Policy); (2) agencies must develop the necessary prerequisites before implementing the practices, and (3) "the prerequisite problem" has been recognized and efforts are being made (e.g. 3rd prong) to address it.

The *messenger* will be unique and responsive insofar as he or she will be drawn from the ranks of transit agency leadership, past or present, will possess all of the qualities necessary to get the attention of fellow CEOs and GMs, and most importantly, will be seen as credible and authoritative. The messenger's credibility will derive from (1) many years of experience in transit, (2) high visibility among peers, (3) success and innovation with technology, and (4) appreciation of the challenges faced by less successful agencies and the different circumstances of agencies and the effects of these differing circumstances on technology implementation. In addition to being viewed as highly credible and authoritative by the target audience of transit agency CEOs and GMs, the messenger must be articulate and persuasive and must strongly believe in the message and have a personal zeal for communicating it. In short, the messenger must be an "evangelist"—a trusted, capable, and highly motivated insider.

The *mechanisms* for dissemination of the study findings will be unique and responsive insofar as they utilize the most recent technologies and forums as well as emerging ones. Candidate technologies include subscription e-mails, RSS feeds, web seminars, video conferencing, e-Zines, podcasts, and wiki-enabled Internet collaboration. (A wiki is "a type of Web site that allows the visitors themselves to easily add, remove, and otherwise edit and change some available content, sometimes without the need for registration. This ease of interaction and operation makes a wiki an effective tool for collaborative authoring."[127])

One of the most promising mechanisms that should be utilized to disseminate and encourage adoption of the findings of this report is the Applied Transit Technology Center that is in development and being championed by the UTA. The development of The Applied Transit Technology Center (described in more detail in Section 2.3) is based on the recognition that agencies need to pool their efforts to address technology challenges, and the Center features activities and approaches consistent with the findings of this study. The Center's theme of agencies helping each other under the direction of their CEOs or GMs is entirely consistent with the assertion here that the "messenger" must come from within the ranks of transit agency leaders. Also, the Center proposes a whole host of knowledge and technology transfer mechanisms of the type that are needed to effectively communicate the results of this study, including new publications, online materials, forums, workshops, roundtables, and web seminars. The Center's intention to have a strong online component dovetails nicely with the notion of creating a specialized, "one-stop-shop" web portal devoted to transit technology best practices and resources that was suggested at the transit leader focus group convened for this study.

4.2.3 Parallel, Additional Activities in the Political/Policy Arena

The third prong of the dissemination/follow-up model focuses exclusively on follow-up actions. The first two prongs of the strategy are expected to be effective in disseminating

[127] Wikipedia, Nov. 2006, http://en.wikipedia.org/wiki/Wiki.

findings and encouraging their adoption (especially if pursued in partnership with entities like the UTA Applied Transit Technology Center). However, the actions described in the first two prongs of the dissemination/follow-up model are not likely, in and of themselves, to solve "the prerequisite problem" faced by so many agencies. Solutions to that problem must be pursued through political and policy-making channels. The objective of activities in the political, policy-making arena is to help make the case to U.S. DOT leadership and elected officials that

1. In order to play its role in meeting the current transportation challenges that will intensify in the future, transit will have to improve.
2. Effective utilization of technology is a primary means of improving transit.
3. Technology cannot be effectively exploited by transit agencies without the proper support and resources. The nature of this support should be carefully aligned with each agency's needs. Deployment funding will be most effective when it is restricted to those agencies with demonstrated prerequisites and a commitment to EAP, change management, ROI analysis, SE, and post-deployment evaluation. For agencies lacking the prerequisites and commitments to change management, post-deployment evaluation, and the other proven and needed techniques, resources provided in the form of technical assistance to help establish the prerequisites and the other commitments will be the most useful.

Activities in this third prong could be undertaken by FTA in partnership with transit industry associations like APTA.

Glossary of Acronyms

AI	Artificial intelligence
APC	Automatic passenger counting
APTS	Advanced public transportation systems
ATIS	Advanced traveler information systems
AVL	Automatic vehicle location
BAP	Business advancement program
BART	San Francisco Bay Area Rapid Transit
BPI	Business process improvement
BPR	Business process re-engineering
BRT	Bus rapid transit
CAD	Computer-aided dispatch
CATS	Charlotte Area Transit System
CBA	Cost-benefit analysis
CBTC	Communication-based train control
CDPD	Cellular Digital Packet Data
CEO	Chief Executive Officer
CH	Clearinghouse
CIO	Chief Information Officer
CIP	Capital Improvement Plan
CMAQ	Congestion Mitigation and Air Quality Improvement
CMTA	Capital Metropolitan Transportation Authority
COTA	Central Ohio Transit Authority
COTS	Commercial-off-the-shelf
CTO	Chief Technology Officer
DARPA	Defense Advanced Research Projects Agency
DBMS	Database management systems
DMS	Dynamic message sign
DSL	Digital subscriber line
DVR	Digital video recorder
EAP	Enterprise architecture planning
EFP	Electronic fare payment
EIO	Expressions of interest

EPS	Electronic payment system
ERP	Enterprise resource planning
FCC	Federal Communications Commission
FDOT	Florida Department of Transportation
GALE	Global Autonomous Language Exploitation
GIS	Geographic information system
GM	General manager
GPS	Global positioning system
IEEE	Institute of Electrical and Electronics Engineers
IPAS	ITS Program Assessment Support
IRP	Infrastructure Renewal Program
ISP	Information service provider
IT	Information technology
ITS	Intelligent transportation systems
ITSC	Information and Technology Strategy Committee
ITSV	The Office of IT and Services
IVHS	Intelligent vehicle highway system
IVR	Interactive voice response
IVS	Intelligent vehicle systems
JPO	Joint Program Office
KSA	Knowledge, skills, and abilities
LACMTA	Los Angeles County Metropolitan Transportation Authority
LADOT	Los Angeles Department of Transportation
LAN	Local area network
MARTA	Metropolitan Atlanta Rapid Transit Authority
MDT	Mobile data terminal
MIT	Massachusetts Institute of Technology
MMDI	Metropolitan Model Deployment Initiative
MMS	Maintenance management systems
MTA	Metropolitan Transportation Authority (New York)
NASA	National Aeronautics and Space Administration
NPV	Net present value
NTI	National Transit Institute
NVTC	Northern Virginia Transportation Commission
NYCT	New York City Transit
ORNL	Oak Ridge National Laboratory
P3	Public-private partnership
PDA	Personal digital assistant
PROTECT	Program for Response Options and Technology Enhancements for Chemical/ Biological Terrorism
PT	Public transportation
QA	Quality assurance
RFID	Radio frequency identification
RFP	Request for proposal
ROI	Return on investment

RSC	Regional service centers
RTD	Denver Regional Transportation District
RSS	Really simple syndication
SAE	Society of Automotive Engineers
SAP	System Access and Capacity Program
SCADA	Supervisory control and data acquisition
SE	Systems engineering
SEPTA	Southeastern Pennsylvania Transportation Authority
SMS	Short message service
TAC	Technology advisory committee
TDM	Transportation demand management
TMC	Transportation management center
TriMet	Tri-County Metropolitan Transportation District
TSP	Transit signal priority
UK	United Kingdom
UPS	United Parcel Service
U.S. DOT	United States Department of Transportation
UTA	Utah Transit Authority
WAP	Wireless application protocol
WEP	Wired equivalent privacy
Wi-Fi	Wireless fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless local area network
WMATA	Washington Metropolitan Area Transit Authority
XML	Extensible markup language

APPENDICES

The following appendices are available on the TRB website at http://trb.org/news/blurb_detail.asp?id=8515:

- Appendix A: Summary of the Transit Agency Leader Focus Group
- Appendix B: Summary of the ITS America 2005 Transit GM Summit.

Abbreviations and acronyms 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