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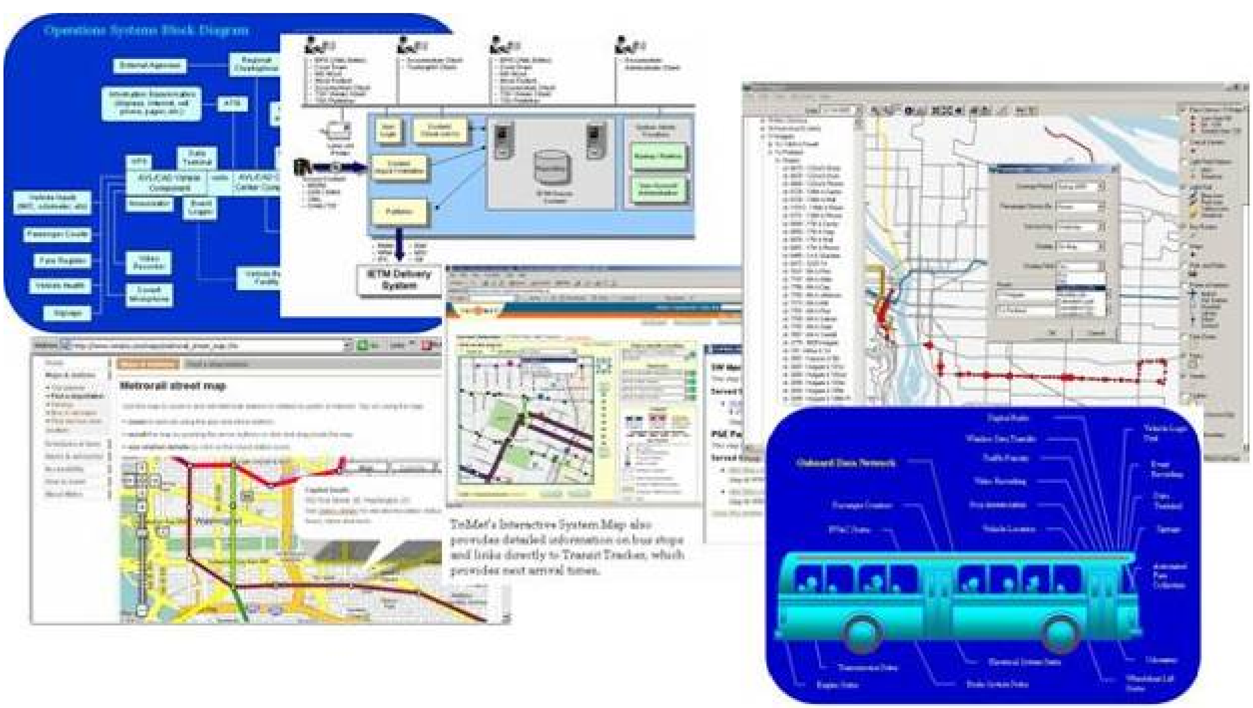
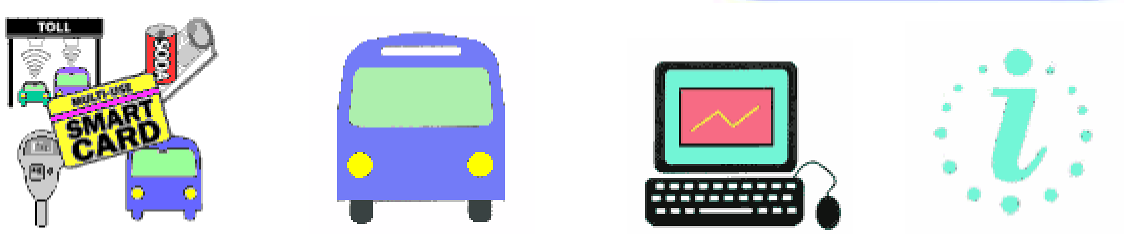
ADVANCED PUBLIC TRANSPORTATION SYSTEMS: THE STATE OF THE ART UPDATE 2006





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13. ABSTRACT (Maximum 200 words) This report is the latest in a series of State-of-the-Art reports, the last of which was published in December 2000. It contains the results of a high-level scan of the extent and character of the adoption and use of advanced technology in the provision of public transportation services in North America. The objective of this effort was to provide a useful and timely reference on the subject of emerging Transit ITS technological advances and trends, and make the information available to public transportation professionals. The report is intended to provide up to date information on the current deployment status of transit ITS technologies, provide lessons learned based on deployment experiences, and promote understanding of future trends in Advanced Public Transportation Systems (APTS).				
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ADVANCED PUBLIC TRANSPORTATION SYSTEMS: THE STATE OF THE ART UPDATE 2006

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FOREWORD

This report contains the final results of a high-level scan of the transit industry, including interviews and analysis, concerning the status of state-of-the-art Intelligent Transportation System (ITS) applications to public transit service in North America. The objective of this effort was to increase the transit community's knowledge of new opportunities, challenges, and lessons learned by agencies and suppliers in applying advanced technologies to improve the efficiency, effectiveness, reliability, safety, and security of public transit services.

Key observations from the research include:

- The complexities associated with state-of-the-art ITS technologies exceed the transit community's current ability to deploy them and stay abreast of ongoing developments.

- Key obstacles include:
  - The stand-alone nature of most individual technology deployments limits the benefits that could be provided by business-oriented, enterprise-wide technology strategies;
  - Most technology-based applications require continuous cooperation and coordination between and among many different departments, agencies, and jurisdictions that are often difficult to achieve;
  - Limited resources and gaps in education and training in the integration, use, and maintenance of technologies and the standards necessary for interoperability and data sharing make it difficult for transit professionals to keep up with technological developments and opportunities;
  - Fast-paced changes in technologies put deployment efforts at risk.

- Looking ahead:
  - The greatest improvements to 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;
  - Federal efforts to provide opportunities for peer group knowledge-sharing, education, and training would help foster a better understanding of opportunities and challenges of state-of-the-art technologies.

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Acronyms and Abbreviations

AAR	Association of American Railroads
ABS	Anti-Lock Brake System
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
APTS	Advanced Public Transportation Systems
AVL	Automatic Vehicle Location
CAD	Computer Aided Dispatch
CBTC	Communications-Based Train Control
COTS	Commercial Off the Shelf
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communication
EIA	Electronic Industries Alliance
FAR	Federal Acquisition Regulations
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GIS	Geographic Information System
GPS	Global Positioning System
HAR	Highway Advisory Radio
HOV	High Occupancy Vehicle
HUD	"Heads Up" Display
ID	Identification
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IT	Information Technology
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation System
IVR	Interactive Voice Response
IVS	Intelligent Vehicle System
JPO	Joint Program Office
LACMTA	Los Angeles County Metropolitan Transportation Authority
LCC	Life Cycle Cost

MDT	Mobile Data Terminal
MPO	Metropolitan Planning Organization
NJT	New Jersey Transit
NHTSA	National Highway Traffic Safety Administration
NTCIP	National Transportation Communications for ITS Protocols
NTI	National Transit Institute
NYCTA	New York City Transit Authority
PC	Personal Computer
PDA	Personal Digital Assistant
PRT	Personal Rapid Transit
RADAR	Short range Radio Direction and Ranging
RF	Radio Frequency
RFID	Radio Frequency Identification
RFP	Request for Proposals
SAE	Society of Automotive Engineers
SCADA	Supervisory Control and Data Acquisition
SOA	State-of-the-Art
TCIP	Transit Communications Interface Profiles
TCRP	Transit Cooperative Research Program
TDM	Transportation Demand Management
TEA 21	Transportation Equity Act for the 21st Century
TMA	Transportation Management Associations
TRB	Transportation Research Board
TSC	Transit Standards Consortium
TSP	Transit Signal Priority
VAN	Vehicle Area Network
VLU	Vehicle Logic Unit
VMS	Variable Message Signs
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
WI-FI	Wireless Fidelity
Wi-MAX	Worldwide Interoperability for Microwave Access
XML	Extensible Markup Language

Executive Summary

This *Advanced Public Transportation Systems: State-of-the-Art Update 2006* is the seventh in a series of reports first established in 1991 by the Federal Transit Administration (FTA) to provide transit professionals with a useful and timely reference on the subject of emerging transit Intelligent Transportation System (ITS) advances and trends.

The concept of ITS, which began in the 1960s in response to increasing traffic congestion, was officially established by the United States Congress in 1991. ITS applies a broad range of technologies to integrate surface transportation infrastructures and vehicles to improve efficiency, safety, and customer service. Advanced Public Transportation Systems (APTS) is the transit component of ITS.

A significant change from past reports is reorganizing the APTS typologies into categories that more accurately reflect ITS advances. A new category titled "Integration," which encompasses the ITS National Architecture and cross-cutting technologies, is placed as the centerpiece of the typology because of its essential role in linking and leveraging ITS applications. Other changes include the addition of information that highlights the importance of agency-wide data and data infrastructure. Some typology subcategories are new or retiled to introduce new terminology, and to highlight many of the underlying support systems and business processes.

Figure 1 shows the updated Transit ITS typology classification. Each major typology heading corresponds to a report chapter. For the reader's convenience, Table 1 highlights selected findings from each chapter. The table includes a general introduction to the topic followed by a brief technology overview, examples of state-of-the-art applications, and a sample of challenges and lessons learned from deploying the various technologies.

Figure 1 Updated Transit ITS Typology

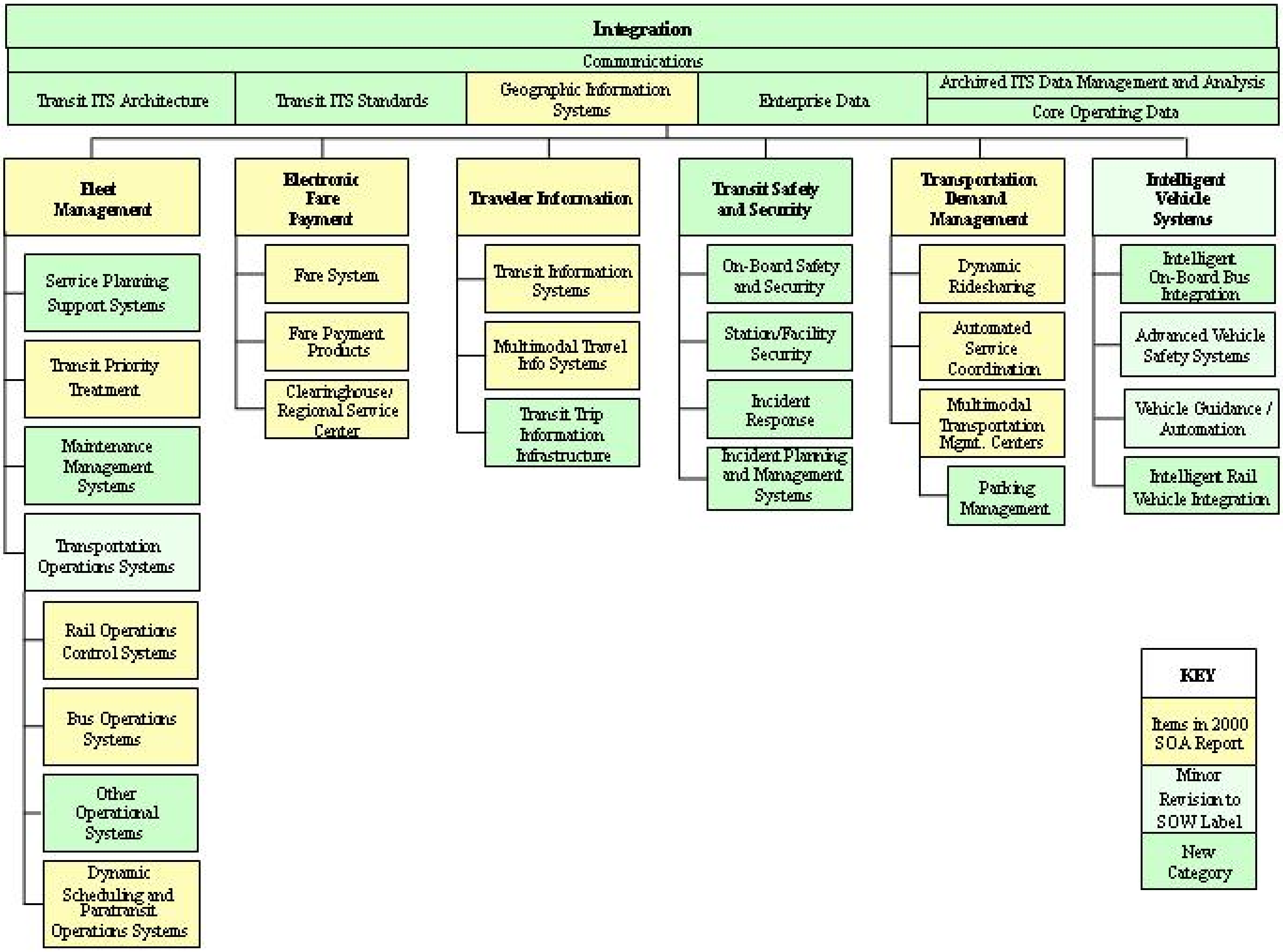


Table 1 APTS State-of-the-Art Update 2006 Highlights

CHAPTER 2: INTEGRATION	
Introduction	• Facilitates a cohesive "system" of interconnected ITS applications that collectively produce services and advantages far greater than any one application could achieve independently
Transit ITS Architecture	
Technology Overview	• The National ITS Architecture serves as the framework for developing integrated transportation systems • Supports regional internal Information Technology (IT)/ITS and project architectures • Enterprise Architecture Planning (EAP) reinforces success
State of the Art	• Regional internal agency and project architecture applications that leverage transit resources, minimize duplication, and offer seamless transit services for customers
Challenges and Lessons Learned	• Important to link agency ITS and IT architectures • FTA's policy regarding systems engineering is extremely important when developing ITS projects • Develop strategies for sharing data resources and data maintenance activities with external organizations
Enterprise Data	
Technology Overview	• Core data used by multiple organizational units and applications describing services, facilities, assets, and other key information • Data management and reporting tools, logical data model, data policies and procedures
State of the Art	• The use of agency-wide or regional data dictionaries, architectures, data models and standards, and integration strategies
Challenges and Lessons Learned	• Manage core service and operational data from an integrated, enterprise-wide perspective • Effective information management requires a plan supported by senior management • Develop a clear set of requirements and reports that meet business needs and challenges before developing applications

Geographic Information Systems (GIS)	
Technology Overview	• Provides tools for creating, managing, analyzing, displaying spatial data, and supporting ITS applications • Spatial data and GIS tools are essential elements of an agency's information technology and ITS infrastructure
State of the Art	• Regional and enterprise-wide GIS systems • LIDAR (LIght Detection And Ranging) data, which provide spatial data with x-y-z coordinates • Internet and desktop tools that provide powerful viewing options of spatial and transit data, including interactive maps
Challenges and Lessons Learned	• Multiple GIS systems and other barriers limit the efficient development, management, exchange, and use of spatial data • Adopt one agency-wide Base Map to maintain and propagate • Integration of both GIS and spatial data efforts can provide some of the biggest integration cost saving benefits in ITS
Communications	
Technology Overview	• Provides data and/or voice communications for transit planning, maintenance, operations, and incident management • Also facilitates coordination with those transportation providers and public safety organizations beyond the transit community • Encompasses a variety of wireless technologies
State of the Art	• Applications that provide: ▪ Seamless interoperability between multiple dissimilar radio systems ▪ Reduction of radio channels through increased use of electronic messaging in lieu of voice communications • Trends include reforming of radio frequency spectrum, new standards, and use of cellular and wireless Internet services
Challenges and Lessons Learned	• Recent disasters illustrate need for transit communications to interoperate with public safety and other regional agencies • Design constraints limit vendor flexibility in meeting core agency needs and may cost more than they're worth • Make use of wireless Internet cooperative funding opportunities; avoid duplicative deployments

Transit ITS Standards	
Technology Overview	• A standard or protocol is a set of rules or measures to compare or build similar objects. U.S. DOT supports standards to accelerate the development, adoption, and deployment of ITS • Use of standards lowers costs over the system life; also facilitates integration and interoperability
State of the Art	• Many standards under development; few actually deployed • Widely implemented standards include SAE J1708 in buses and IEEE 1473 in trains • Trend toward greater use of standards
Challenges and Lessons Learned	• Map requirements to standards before specifying them in procurements and build on IT standards • Regional systems require regional data integration strategies • Systems can require multiple standards working together to ensure interoperability

CHAPTER 3: FLEET MANAGEMENT	
Introduction	• Use of technology to plan, supervise, and optimize the delivery of transit services and maintaining vehicles • Technologies are vast and include in-vehicle, field, and operations center systems such as: ▪ Automatic Vehicle Location ▪ Computer-Aided Dispatch ▪ Automatic Passenger Counters ▪ Transit Signal Priority
Service Planning Support Systems	
Technology Overview	• Infrastructure that supports the flow of information between the various fleet management systems • Processes and interprets large volumes of data for reporting purposes

State of the Art	• Accurate accounting and reporting of ridership • Automatic reporting of failed equipment • Automatic calculation of run times for scheduling • Standards-based modular architecture and multi-vendor component interchangeability • Trends include map-based tools for maintaining passenger stop and pattern data
Challenges and Lessons Learned	• Optimizing the reporting capabilities of advanced systems to achieve the desired results • Efforts to share schedules and stop inventories electronically are hindered by a lack of complete and consistent data • Define an enterprise data model for stop, pattern, and schedule information • Develop process for data maintenance and updating
Transit Priority Treatment	
Technology Overview	• Systems detect approaching transit vehicles and alter signal (i.e., traffic light) timings to improve transit performance and reliability
State of the Art	• Intelligent, rule-based systems that determine need for priority treatment based on many factors • Trends include advanced systems that manage signal priority in an effective manner without disrupting overall traffic flow
Challenges and Lessons Learned	• Obtaining support from local traffic engineers • Lack of funding, technology understanding and inadequate infrastructure capabilities
Maintenance Management Systems	
Technology Overview	• Onboard vehicle component "health" monitoring and other systems to improve maintenance effectiveness and efficiency • Includes monitoring of fluids, warranty, inventory, and records management; and remote vehicle diagnostics
State of the Art	• Advanced systems that monitor equipment status in real time and report failures immediately to prevent more costly repairs • Automatic transfer of vehicle data as vehicle enters the facility • Single-point-of-maintenance data access for all commuter rail vehicle systems • Trends include systems that predict failures in advance

Challenges and Lessons Learned	● Tracking and detecting repeat failures; solution is to tag field-replaceable units with electronic serial numbers
Transportation Operations Systems	
Technology Overview	● Agency-based systems that support real-time operations of transit fleets. Includes: ▪ Rail Operations Control Center Systems ▪ Bus Operations Control Center Systems ▪ Other Operations Systems (ferries, facilities, HOV, multimodal) ▪ Paratransit Operations Systems
State of the Art	● Systems that provide a complete "picture" of the current status of the entire transit operation ● Trends include: ▪ Integration with passenger information and maintenance management ▪ Use of archived data to facilitate scheduling
Challenges and Lessons Learned	● Inadequate definition of business requirements; be specific and make priorities understandable ● Inadequate final acceptance testing of computer systems; develop test plan based on original business requirements ● Use care when specifying compliance to standards ● Risks associated with custom development

CHAPTER 4: ELECTRONIC FARE PAYMENT	
Technology Introduction	● Provides automated means of collecting and processing fares for public transportation services ● Includes: ▪ Fare Systems ▪ Fare Products (Media) ▪ Clearinghouse/Regional Service Center (CH/RSC)

Challenges and Lessons Learned	• Difficulty in implementing regional fare collection systems due to hardware/software issues and ineffective working relationships • Resolve fare policy issues, business rules and revenue reconciliation issues early and in parallel with other activities • Involve regional partners in each development stage • Standards help ensure fare integration and interoperability • Have a clear vision of what is expected from an electronic fare system and clearly articulate vision and requirements
Fare Systems	
Technology Overview	• Includes various functions and equipment used by a transit agency to deploy a fare collection system
State of the Art	• Universal electronic fare payment system for multiple modes • Farebox as single-point logon for bus operators • Electronic media used for fares and as identification cards • Internet sale of fare products • New systems that provide accurate and timely revenue data
Fare Payment Products (Media)	
Technology Overview	• Includes magnetic stripe cards, credit cards and smart cards
State of the Art	• Multifunction, contactless proximity smart cards • Limited use (disposable) smart tickets • Trends include regional, multimodal contactless smart card systems
Clearinghouse/Regional Service Center (CH/RSC)	
Technology Overview	• Provides a regional fare system with clearing, settlement and associated financial reports and management information • Technology driven by need to provide a high volume, secure transaction processing center
State of the Art	• Centers having a well-developed and thought-out institutional framework supported by technology • Trends include emerging standards that will make regional payment system deployments easier in the future

CHAPTER 5: TRAVELER INFORMATION	
Introduction	• Provides convenient information access to assist travelers to learn about and use public transit • Also assists agency staff in locating information to improve transit services
Challenges and Lessons Learned	• Difficulty in developing accurate, timely and complete data • Allow adequate time to develop needed data • Well thought-out processes and resources are needed to effectively address ongoing data maintenance needs
Transit Information Systems	
Technology Overview	• Traveler information obtained per trip (to plan a trip or verify information at trip commencement) or during a trip • Personal systems: information accessed through cell phones, personal digital assistants, and laptop computers • In-terminal systems: information provided at bus stops, terminals, train stations, and platforms • In-vehicle systems: announcements or signs on transit vehicles
State of the Art	• Improved database tools and Web services allow more specific query options for customers and staff • New geographic tools and Web mapping allow easier and better querying and displaying of geographic data • Improved speed and accessibility of wireless communications
Multimodal Travel Information Systems	
Technology Overview	• Makes use of multiple channels (call centers, kiosks, Internet, telephone, cell phones, PDAs, pagers, etc.) to provide real-time and static information on transit, traffic, and other modes • Allows travelers to make fully informed mode choice decisions both pre-trip and enroute
State of the Art	• 511 telephone and Web applications • Advanced trip planning systems to provide best travel options
Transit Trip Information Infrastructure	
Technology Overview	• "Behind the scenes" tools and procedures to provide accurate data for trip information services locally and region-wide

State of the Art	● Advanced data infrastructures that operate in an integrated manner, both internally and regionally ● Trends include use of wireless communications, Web tools, geographic information, mapping tools and data management techniques to improve traveler information services

CHAPTER 6: TRANSIT SAFETY AND SECURITY	
Introduction	● Use of technology to improve the safety and security of transit ● Security addresses intentional acts of crime or violence ● Safety deals with unintentional harm to people and physical assets
Challenges and Lessons Learned	● Lack of communications interoperability between and among systems due to lack of equipment and data standards ● Populating systems with timely, accurate, and usable data requires leadership to engage regional partners ● Also requires sustained commitment to acquiring and maintaining data to effectively manage incidents ● Overall plan that clearly identifies responsibilities is crucial in the event of a major safety or security incident
Onboard Safety and Security	
Technology Overview	● Includes onboard voice communications (radio) and video assessment (camera surveillance) technologies
State of the Art	● Deployment of "broadband communications corridors" using the Internet to transmit data to and from vehicles; may provide future platform for interoperable voice/data communications ● Limited video advancements onboard transit vehicles; real-time transmission limited to low resolution, black and white images due to bandwidth constraints ● Trends include improvements in bandwidth technology to transmit high-density digital video from moving vehicles
Challenges and Lessons Learned	As with all other onboard systems, a major challenge will be to effectively and efficiently integrate voice and data systems with other onboard systems
Station/Facility Safety and Security	
Technology Overview	● Video assessment systems that monitor activities at transit stations and facilities

State of the Art	● Effective video systems that are well-specified, deployed, maintained and operated by knowledgeable and engaged users ● Trends include making digital video accessible from PCs or PDAs using Internet access protocols
Challenges and Lessons Learned	● Video assessment systems enhance overall safety and security programs by providing visual and audio evidence of incidents ● New video assessment systems should be integrated with existing administrative and other business systems to enhance overall effectiveness of data collection and analysis
Incident Response	
Technology Overview	● Technologies include chemical detection, Web-based information and radio and cell phone-based communications systems
State of the Art	● Significant progress made in testing and deploying chemical detection systems at several major transit systems ● National and local 511 efforts are beginning to provide a platform for evacuation information for evacuees ● Despite dropped calls and switch capacity constraints that result in busy signals, cell phones have become the tenuous means of communicating during an emergency
Challenges and Lessons Learned	● Testing procedural aspects of the use of detection technology are as important as testing the hardware and software components ● Getting appropriate, timely information collected, assessed, formatted, and transmitted to the affected population in an emergency is critical to successful technology implementation ● Radio interoperability for effective communications among emergency responders remains elusive, resulting in dependence on commercially available cell phone technology that does not provide reliable and secure transmission of voice or data
Incident Management and Planning Systems	
Technology Overview	● Provide a way to collect and organize data to help transit agencies make critical incident and disaster response management more efficient and effective
State of the Art	● Limited transit applications to date ● Trends include live digital video feeds from remote locations overlaid on a geographic map and linked directly into a routing plan for emergency evacuation

Challenges and Lessons Learned	● The collection, management and maintenance of data and information from multiple departments and agencies require keen leadership and team-building skills, as well as significant staff resources to ensure that data and information are kept up-to-date ● Interoperability with other emergency command centers falls short due to the proprietary nature of procured systems

CHAPTER 7: TRANSPORTATION DEMAND MANAGEMENT	
Introduction	● Reduces the impact of traffic by influencing travel behavior ● "Big picture" strategic solution for mobility problems that ITS was originally created to address
Dynamic Ridesharing	
Technology Overview	● Paratransit-like service allows travelers to be joined in real time to provide taxi-like responsiveness ● Makes use of many technologies: call centers, Internet-based ridematch, automobiles, and automated personal rapid transit
State of the Art	● "Next day" responsiveness has been achieved ● However, "dynamic" ridematching (i.e., pairing riders with hosts in real time) has not yet been successfully implemented ● Trends include: ▪ Technology improvements that reduce lead time requirements for trip requests ▪ Use of Internet to facilitate statewide ridematching
Challenges and Lessons Learned	● Integrating paratransit with supplemental subscription services improves net operating results ● Paratransit vehicles with enhanced systems require robust onboard electrical systems ● Geographic-based software systems require an accurate base map; also need to be maintained on a continual basis
Automated Service Coordination	
Technology Overview	● Technologies, policies and procedures that guarantee passenger transfers during a fully linked trip ● Makes use of automatic vehicle location, electronic fare collection, decision support systems, and mobile data terminals

State of the Art	• Current systems use real-time vehicle location information, but apply simplistic decision tools to protect a particular connection • Auto-dial and e-mail notification capability to alert subscribing customers of service disruptions and delays • Trends include next generation of decision-support tools to improve connection protection capabilities
Challenges and Lessons Learned	• Complexity makes benefits difficult to achieve and assess • Agencies need to gather information on a regular basis to evaluate their effectiveness
Multimodal Transportation Management Centers	
Technology Overview	• Links traffic and transit operations centers to optimize network performance across multiple transportation modes • Various technologies monitor highway and transit performance, detect congested conditions, notify affected agencies, identify available assets, coordinate a unified response and track results
State of the Art	• Emergency management centers that combine traffic, transit and emergency planning and management under a single entity • Trends include real-time public transit parking information systems
Challenges and Lessons Learned	• Much effort is required to coordinate and maintain multimodal transportation information at a regional website • Most project plans have grossly underestimated the effort required • The migration to an integrated management center is best made incrementally, one application at a time

CHAPTER 8: INTELLIGENT VEHICLE SYSTEMS	
Introduction	• Onboard systems that collect, compare and process data to inform and/or take corrective action
Challenges and Lessons Learned	• Devices with proprietary interfaces; build careful controls regarding locally defined codes and data link escape • Infrastructures or architectures that limit functionality; consider other functions in the design stage • Vehicle networks are best installed during initial vehicle assembly

Intelligent Onboard Bus Integration	
Technology Overview	• Allows various stand-alone equipment found on a transit bus to interoperate with each other • Maximizes functionality, reliability, usability, efficiency, and effectiveness of the overall transit operation; also reduces costs
State of the Art	• Onboard network architecture that provides maximum interoperability and multi-vendor interchangeability • Single-point operator sign-on • Trends include migration from application-specific networks to IT standards and PC operating systems (e.g., Windows)
Advanced Vehicle Safety Systems	
Technology Overview	• Collision warning, obstacle detection, road departure warning, vision enhancement, and other vehicle safety systems • Routine in trucking; limited use in transit
State of the Art	• Single reported U.S. transit application includes side collision warning system • Trends include increased penetration of these available technologies to transit vehicles
Vehicle Guidance/Automation	
Technology Overview	• Navigation and route guidance systems, precision docking systems, adaptive cruise control systems, and coupling/decoupling systems to reduce driver workload
State of the Art	• Single reported U.S. transit application includes precision bus docking application for platform-level boarding • Trends include electronic lane-keeping assistance systems
Intelligent Rail Vehicle Integration	
Technology Overview	• Allows various stand-alone equipment found on a railcar or locomotive to interoperate with each other • Maximizes functionality, reliability, usability, efficiency, and effectiveness of the overall transit; also reduces costs
State of the Art	• Multi vendor interchangeability of radio systems, event recorders, mechanical components and others • Interchangeability extended to car-borne control and information systems to allow higher level of interoperability • Trends include standards for sign and voice annunciator systems

Chapter 1 Introduction

1.1 Background

This report documents work performed under the FTA's Advanced Public Transportation Systems (APTS) Program, a program structured to undertake research and development of innovative applications of advanced navigation, communication, information, computer, and vehicle technologies that most benefit public transportation.

The Advanced Public Transportation Systems State of the Art Update 2006 *(APTS SOA Update 2006)* is the seventh in a series of ongoing informational reports, the last of which was published in December 2000. It summarizes the results of a limited investigation on the progress of implementing Advanced Public Transportation Systems technologies throughout the nation. The objective of the report is to provide information that will lead to an enhancement of the public transportation industry's knowledge on the application of advanced technologies.

This report was conducted by the Palisades FTA Omni Team and was sponsored by the Office of Mobility Innovation of the Federal Transit Administration.

1.2 New Report Approach

A new approach was taken for this edition to provide a useful and timely reference on the subject of emerging transit ITS technological advances and trends. Efforts focused on highlighting successful ITS applications, revealing the lessons learned along the way, and identifying the issues and hurdles to help other agencies replicate SOA applications in an efficient and successful manner.

A substantial effort was made to seek out, survey, and interview knowledgeable transit personnel and to document the findings and recommendations for national policy as well as specific types of federal technical assistance. The report describes some of the newest technologies and provides real-world examples of state-of-the-art applications of those technologies. Challenges and lessons learned are documented and conclusions are drawn to provide input to FTA for its transit ITS planning and programming assistance efforts.

1.3 Defining "State of the Art"

For this report, the research team identified "state-of-the-art technologies" in both objective and subjective terms. Technologies were selected for inclusion in the report based on combined criteria such as a technology's newness, best application, best business results, and greatest potential. As a result, the report reflects, in good measure, the "state of the art" in defining and interpreting the "state of the art" in Transit ITS.

1.4 New Typology Organization

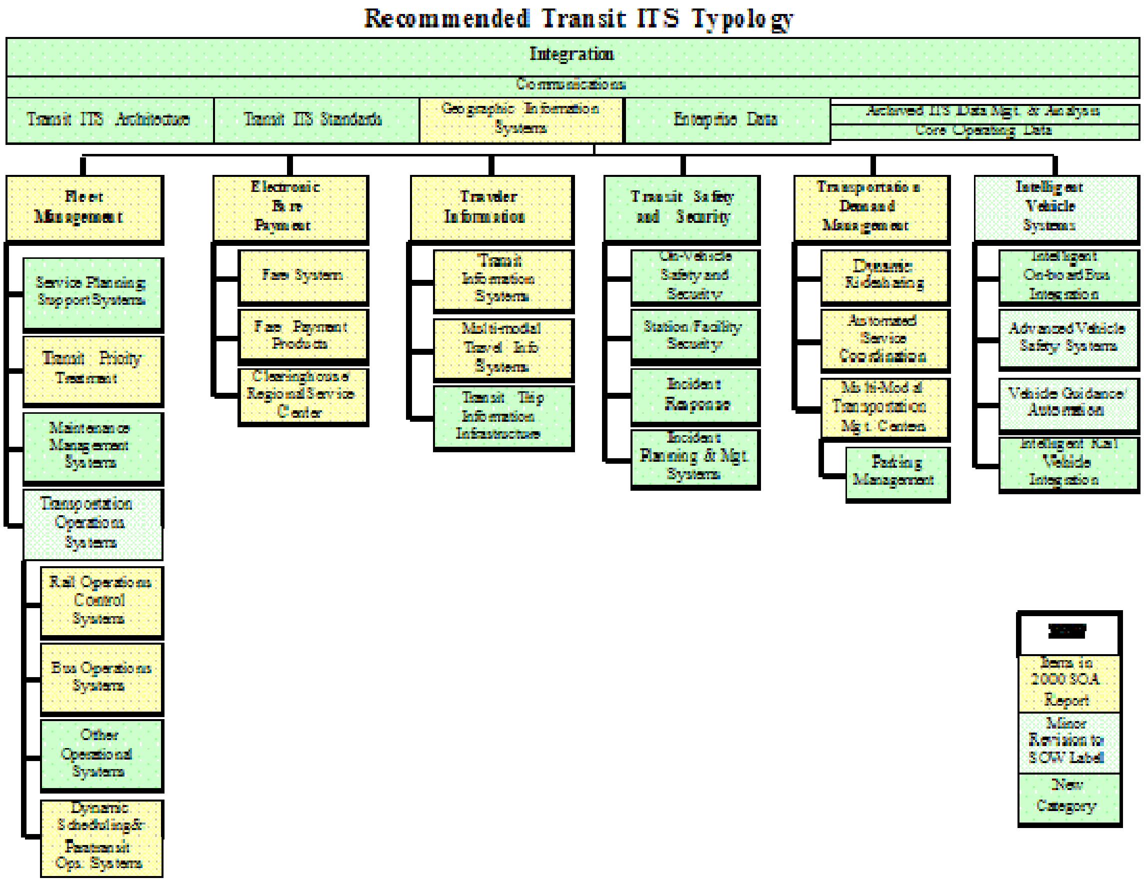
In the past, the Federal Transit Administration (FTA) has supported the development of ITS typologies, which organize and classify the various ITS applications in transit. Over time, the typologies require updating to incorporate the various changes and advances as ITS developments are refined and new ITS efforts emerge.

The *APTS SOA Update 2006* is based on a revised and expanded ITS typology (subject classification system). The updated typology classification builds upon past typologies and considerations for other typology efforts currently under way, and provides the report with a cogent framework to highlight successful ITS applications, reveal the lessons learned along the way, and identify the issues and hurdles to help other agencies replicate SOA applications in an efficient and successful manner.

The SOA 2000 report typology featured five major categories, which have been expanded to seven for the SOA 2006 report (See Figure 2). To refine the typology, past transit ITS typologies were reviewed with respect to each other, and considerations were given to other typology development efforts under way and to recent ITS advances and issues. The report typology used the following objectives as guidance:

- Establish a simple, clear method to classify the ITS elements with the least amount of redundancy;
- Ensure that the approach established to classify ITS is consistent with:
  - Transit organizations and their glossary,
  - National ITS Architecture categories, and
  - FTA benefits and program categories;
- Incorporate new advances in ITS technologies since the last SOA Report and support changing transit business processes; and
- Support information consistency and transferability with prior SOA reports and the ITS Impact Matrix typology.

Figure 2 Recommended Transit ITS Typology



Central to the typology of this report is the new category titled "Integration," which includes communication, architecture, standards infrastructure, data, emerging technologies, and business processes and software needed to successfully implement transit ITS. The importance of this topic is such that it deserves its own place as a central typology category, linking all agency ITS applications into an integrated system that allows it to operate and provide passenger services more efficiently, and to exchange data with other transit agencies and transportation providers. This new category not only addresses integration within transit itself, but serves to link transit with other, more universal transportation providers.

Integration encompasses the ITS National Architecture and ITS Standards, as well as core elements of a successful transit ITS infrastructure. The subject of information technologies (IT) is also addressed to highlight the importance of accurate, timely agency-wide data. Like the previous typologies, each of the major categories contains subcategory branches with specific applications. Since integration is essential to ITS in that it facilitates a "system" of interconnected ITS applications that collectively produce services and advantages far greater than independent ITS applications could achieve, it is placed as the centerpiece of the ITS typology and links the other six major categories.

Transit Safety and Security, which addresses the systems and technologies that deal with the safety and security of transit customers, personnel, equipment, and facilities, has been expanded to address Disaster and Incident Management Planning Support Systems. Other significant changes to the recommended typology include new nomenclature to reflect recent ITS developments, understandings, and terminologies. Also included are new or retitled subcategories that address many of the important but often overlooked programs, support systems, and business processes that have been kept "hidden" in previous ITS typologies.

1.5 Intended Audience

The intended audience for this report consists of transit decision makers and management staff.

1.6 Report Objective and Methodology

1.6.1 Report Objective

The capabilities of ITS greatly exceed the current practice and will continue to do so as new technology applications are discovered. The purpose of this report is to help agency decision makers keep pace with ITS by focusing on state-of-the-art applications, and the challenges and lessons learned from those applications (not on state-of-the-practice, as this information is available in other reports). The report is intended to give agencies a better understanding of:

- The various major technologies that make up ITS;
- The capabilities and limitations of those technologies;
- Exemplary successes achieved by those agencies that represent the state of the art in ITS deployments;
- The lessons learned along the way and the obstacles conquered to achieve those successes;
- The issues and hurdles that agencies need to overcome themselves to help streamline ITS deployments; and
- What the future holds for major ITS technologies.

1.6.2 Report Methodology

The revised ITS typology for this report, which captured all significant ITS applications and is consistent with industry efforts to standardize ITS classifications, provided the framework for the report structure and subsequent project research and information-gathering activities.

The research team reviewed relevant literature published during the last two years which included relevant material on ITS technological advances, recent procurements and deployments of ITS systems, integration of ITS technologies, intermodal applications, and interagency coordination of ITS technologies. Materials reviewed included but were not limited to materials already developed by USDOT and FTA and information from publications and websites available from the American Public Transportation Association (APTA), ITS America, the Transportation Research Board (TRB) and others.

Appropriate personnel at the FTA regional offices were contacted for their input regarding agencies with SOA deployments. Press releases announcing the SOA report were sent to trade publications as another method of soliciting SOA information from the transit community, and an online survey questionnaire was distributed to more than 1,800 transit professionals; responses from more than 40 professionals provided information to the research team (see Appendices A and B).

Based on the literature review, responses to the survey questionnaire, and the research team's own understanding of ITS, information was summarized and synthesized under the major ITS typology groups as defined for this report, and a minimum of three transit agencies were identified with state-of-the-art deployments. Transit agency experiences remained the focus. Vendor names with advanced ITS technologies or applications were not used to avoid the potential of appearing to promote one product over another; however, vendors were interviewed to provide their perspective concerning the issues and hurdles associated with ITS implementations.

1.7 Report Organization

This report focuses on seven types of services/technologies: Integration, Fleet Management, Electronic Fare Payment, Traveler Information, Transit Safety and Security, Transportation Demand Management, and Intelligent Vehicle Systems.

For each of the ITS typology categories, concise overviews of APTS technologies are provided and current state-of-the-art and emerging trends, state of the practice, and challenges and hurdles to implementation are discussed.

Chapter 2 Integration

2.1 Introduction and Technology Overview

Now that transit agencies are implementing multiple ITS technologies and regional ITS projects are being deployed, consideration of integration issues and the development of integration strategies is of critical importance. If a transit agency is to reap the full benefits of its investments in ITS and avoid unnecessary or redundant use of resources, the agency must consider integration options to ensure a sound information technology infrastructure, successful ITS projects, and reasonable ongoing maintenance requirements.

This chapter will cover a wide range of possible integration opportunities and strategies that can benefit transit agencies and their customers. For example, it will discuss integration with respect to:

- Regional ITS Architectures;
- Enterprise Architectures and other information technology systems;
- Data management;
- Geographic Information Systems (GIS);
- Communications;
- ITS standards;
- Management support; and
- Policies and procedures.

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.

2.1.1 Need for Integration

The need for integration of transit data and ITS systems is driven by many factors. First and foremost, transit customers are best served by seamless travel options and information as they traverse between the various travel modes and transit providers. Transit technology personnel also need some level of systems and data integration to ensure interoperable and supportable systems. Budget and funding constraints also drive the need for minimal redundancy and greater efficiencies.

To improve the effectiveness of the overall transit operation, each staff member must have access to information in a transparent and seamless fashion, despite the fact that information needed by transit business users is often spread throughout various business applications in different agency departments. Without an integrated approach to creating, managing, analyzing, and accessing information, obtaining needed information can be slow, costly, and at risk. This is especially true if only a few key staff know how to access that information.

In addition, to facilitate the integration of transportation services and the leveraging of resources, the U.S. Department of Transportation (USDOT) has implemented policies, rules, and programs to guide and support transit's integration efforts.

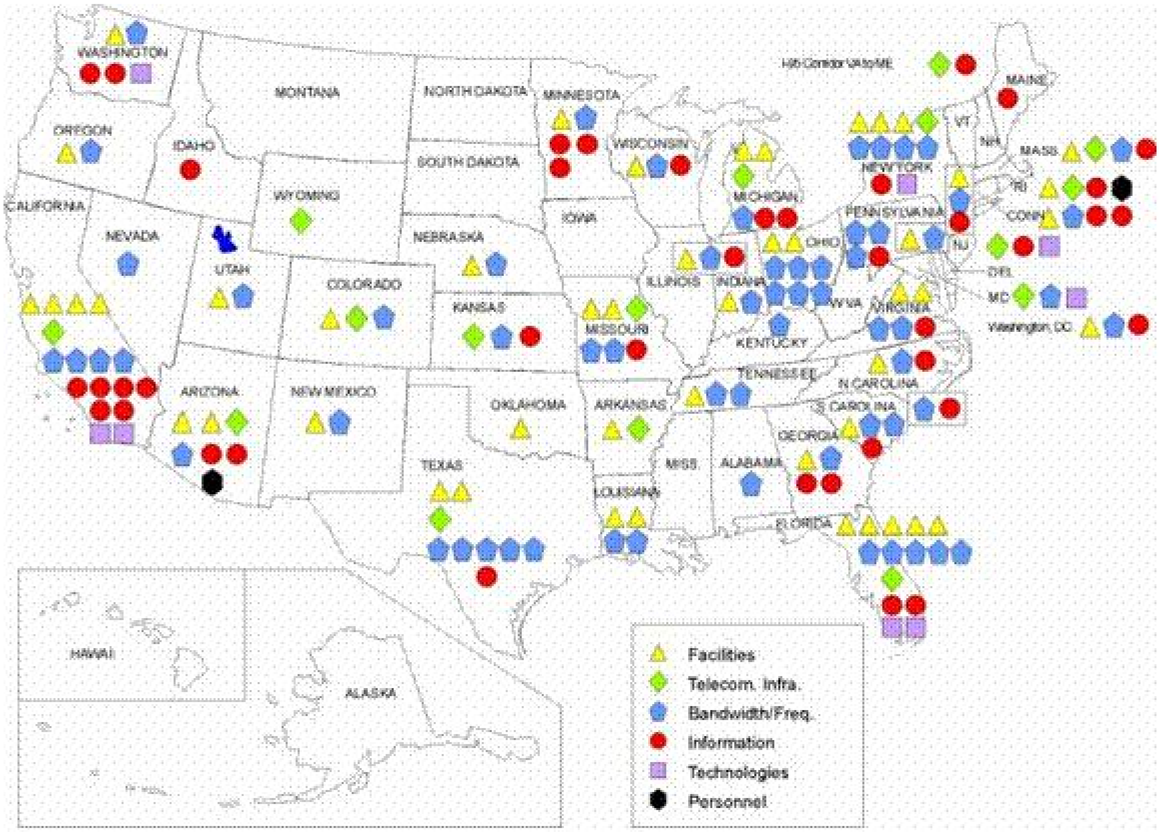
Opportunities for reaping benefits through integration, sharing communications resources, and leveraging investments abound in ITS and transit. Figure 3, taken from a report by Oak Ridge National Laboratories[1] on shared ITS communications involving transit, displays the many locations throughout the U.S. where transit organizations have shared one or more of the following:

- ITS technologies;
- Telecommunications infrastructure;
- Bandwidth;
- Information;
- Facilities; and
- Personnel.

Through this networking, transit agencies and their customers have realized benefits from integrating or sharing information and systems technologies with other ITS applications, departments, transit agencies, DOTs, toll agencies, cities, counties, government councils, utilities, emergency service organizations, private agencies, and others.

[1] "Shared Communications: Volume I. A Summary and Literature Review," by Oscar Franzese, Tykey Truett, and Edmond Chin-Ping Chang, was completed in 2004.

Figure 3 Locations with Shared ITS-Related Resources



From "Shared Communications: Volume I. A Summary and Literature Review"[2]

2.1.2 Integration Subcategories

This section on integration focuses on the topics shown in Table 2 that cut across all areas of ITS, including ITS architecture, enterprise data, Geographic Information Systems (GIS), communications, and transit ITS standards.

[2] *Ibid*.

Table 2 Integration Subcategories

#	Subcategories	Description
2.2	**Transit ITS Architecture**	Processes, procedures, and benefits that relate to the National ITS Architecture and compliance with the FTA Policy. Also includes agency level IT/ITS architectures and project architectures.
2.3	**Enterprise Data**	Includes discussion of the data infrastructure necessary to support a modern transit agency, including archived data as well as real-time operating data and spatial data.
2.4	**Geographic Information Systems (GIS)**	The software, hardware, and data that are needed to create and manage spatial data, perform spatial analyses, produce maps, and distribute spatial data sets. This tool has application throughout the transit organization, including for communicating with customers, regional partners, and other stakeholders.
2.5	**Communications**	Media and equipment used for voice communications and/or data transfer for transit operations, and for communicating with customers and regional partners. Communications systems support onboard, mobile, and fixed-end equipment and applications.
2.6	**Transit ITS Standards**	Information technology (IT) and intelligent transportation system (ITS) standards relevant to the deployment of transit ITS.

If architecture planning and a range of integration strategies are not in place, transit agencies face greater challenges in integrating disparate ITS systems, databases, communications systems, and other automated systems into a single enterprise-wide business support infrastructure. Furthermore, they may miss opportunities to leverage resources, improve service quality, simplify maintenance requirements, and avoid redundant efforts (e.g., paying for and implementing redundant hardware, software, and databases).

A well-conceived communications infrastructure is absolutely critical to the successful systems integration and implementation of ITS applications, including communicating between systems and modes within a transit agency, and communicating with external stakeholders such as customers and other transportation providers. Adequate communications and network capacity must be available when new ITS applications are implemented or the resulting "slow access to data can stall critical operations and cause recurring costs in lost productivity."[3] Communications-related planning also helps to avoid unnecessary redundant costs and labor, such as the possibility of placing multiple antennas, wiring harnesses, and other equipment onboard vehicles to support multiple ITS projects such as Automated Passenger Counters (APC) and Automated Vehicle Location (AVL). Finally, opportunities for cost sharing and better incident management can occur when communications integration exists with emergency services organizations.

GIS and Enterprise Data are critical for supporting most ITS applications and decision-making functions. Core data, such as bus stop, schedule, and route location information, are used enterprise-wide by multiple systems and functions. Time and cost efficiencies, as well as service quality improvements, are possible when core data is created, managed, analyzed, and distributed with an integrated, enterprise-wide perspective. This approach can minimize problems such as having to do follow-up field collection of bus stop data, having incompatible base maps, manually doing multiple updates of the same route data in different databases, having to learn and support too many ad hoc analysis and reporting tools, and many other issues.

This chapter specifically focuses on the:

1. Benefits to transit agencies resulting from integration and using the National ITS Architecture and ITS Standards;
2. Overview and description of the National ITS Architecture and Transit ITS Standards;
3. Information Technology and ITS architectures internal to transit;
4. Use and benefits of systems engineering principles;
5. The importance of communications in ITS systems integration;
6. Roles of an agency-wide GIS and Enterprise Data in supporting and integrating ITS applications and minimizing redundant data maintenance efforts; and
7. SOA integration examples.

2.1.3 Institutional Support of Integration and Sharing

For ITS projects to be successful, integration must occur on many fronts. Hardware, software, data, and communications are typically the focus of integration efforts. However, management support, institutional relationships, and communications must also be in place. Numerous ITS assessments have identified the importance of managing "people and process" issues and other institutional considerations.[4]

[3] From "Turning Transportation On," published in *Intelligence and Warning America* in March 2004. www.netscout.com/docs/reprints/NetScout_reprint_IWA_Turning_Transport_On.pdf.
[4] For example, Technology Solution Providers' "Assessment of ITS Deployments: Draft Final Report." The importance of managing institutional issues is also discussed in "Shared Communications: Volume I. A Summary and Literature Review," by Oscar Franzese, Tykey Truett, and Edmond Chin-Ping Chang.

Managing relationships between business entities is an important aspect of managing "people and processes." If a relationship between two operating entities does not exist prior to ITS technologies being deployed, then one will not necessarily work just because agencies purchase expensive hardware, design and install software, create data, and build interfaces. In fact, implementing an ITS project can strain an existing relationship between two entities because it will probably require compromises from both parties on everything from determining functional specifications to defining the criteria for success.

Critical success factors for integration include:

- ITS architecture planning at both the agency and regional levels;
- Management leadership to encourage work groups to have a broader agency-wide perspective than their own business area or ITS project;
- The disciplined use of a systems engineering approach;
- Appropriate investment levels to support enterprise data management and a technology infrastructure; and
- The application of integration-related policies, technical principles, and standards.

2.2 Transit ITS Architecture

The U.S. Department of Transportation (USDOT) recognized the need to integrate transportation services between modes and regionally to benefit customers and to leverage resources. To help facilitate integrated transportation services and ITS systems, the USDOT invested in a number of initiatives such as the development of the National ITS Architecture, a National ITS Architecture Consistency Policy for Transit Projects, and a similar Rule for the Federal Highway Administration.[5]

The National ITS Architecture is a framework for developing integrated transportation systems. An "architecture" helps define all the key components of what is being built and how they all relate to one another. Standards and protocols help ensure that all the components "fit" together, ideally in an organized and efficient manner. In particular, the National ITS Architecture addresses both logical and physical architecture elements.[6] A logical architecture focuses on the functional processes and information flows of a system. A physical architecture takes the processes identified in the logical architecture and assigns them to physical entities (called subsystems in the National ITS Architecture). The National ITS Architecture helps identify processes and data flows

[5] See ITS Architecture Implementation Program information from the USDOT at: www.ops.fhwa.dot.gov/its_arch_imp/index.htm.

[6] Additional information about the National ITS Architecture is described at the following site: www.iteris.com/itsarch/index.htm.

among ITS subsystems and centers. Further, it serves as a resource for developing regional and project architectures.

Additional discussion of the FTA policy, including the regional ITS architecture and systems engineering provisions, is included in Section 2.2.1 below. A discussion of standards is included in Section 2.6.

2.2.1 Technology Description

Three levels of Transit ITS Architectures can support each other and contribute to the success of ITS. Transit ITS architectures can be:

1. Regional ITS Architectures that show high level ITS relationships with ITS efforts in other agencies, or other aspects of ITS such as Emergency Management or Traffic and Travel Management;
2. Agency-specific IT/ITS architectures; and
3. ITS project architectures.

The FTA ITS Policy that guides use of the National and Regional ITS Architectures is described in Section 2.2.1.1. Regional ITS Architectures are briefly described in 2.2.1.2. An important element of the FTA ITS Policy that helps drive the success of ITS implementation efforts is the systems engineering requirements, which are discussed in Section 2.2.1.3. Transit Internal Architectures are described in Section 2.2.1.4.

2.2.1.1 FTA Policy

A relatively recent FTA policy affects transit procurements and implementations of ITS applications. On April 8, 2001, FTA's National ITS Architecture Consistency Policy for Transit Projects went into effect. As of April 8, 2005, this policy requires that all ITS projects funded by the Highway Trust Fund and the Mass Transit Account must be part of a regional ITS Architecture, use a systems engineering approach during development, and use ITS standards adopted by USDOT.[7] The policy stipulates that:

> *The final design of all ITS projects funded with highway trust funds shall accommodate the interface requirements and information exchanges as specified in the regional ITS architecture. If the final design of the ITS project is inconsistent with the regional ITS architecture, then the regional ITS architecture shall be updated.*

The goals of the ITS Architecture Policy are to:

- Facilitate seamless travel in a region by improving integration between travel modes and service providers;
- Increase regional information sharing to support public transportation;
- Reduce design costs and development times for new systems;

[7] At the time of this report, no ITS standards have been officially adopted by the USDOT.

Lower risks;
Leverage funding in a region; and
Prepare for future expansion.

2.2.1.2 Regional ITS Architecture

Key aspects of developing the Regional ITS Architecture include collaboration among internal and external organizations, and the building of the regional architecture based on the National ITS Architecture. The National ITS Architecture identifies transit "processes" (which are bundled into equipment and market packages) as building blocks of the multimodal transportation system. Transit linkages to other "processes" are identified and highlight transit's integral role in the regional transportation network.

A key provision of the regional planning process is to identify what and how information is shared among transportation organizations and stakeholders. The full benefits of ITS are realized with the integration of regional-wide data. Elements of the Regional ITS Planning Process include the need to:

Identify regional stakeholders and ITS inventory;
Identify needed transportation services;
Identify WHO needs to exchange information;
Identify WHAT information needs to be exchanged;
Identify transit needs and opportunities for data integration in joint ITS projects; and
Define agreements.

2.2.1.3 Systems Engineering Requirements and Procurement Implications

In addition, to be in compliance with the Policy, all eligible ITS projects are required to be developed with the use of a systems engineering approach that includes the following elements:

A description of the scope of the ITS project;
An operational concept that identifies the roles and responsibilities of participating agencies and stakeholders in the operation and implementation of the ITS project;
Functional requirements of the ITS project;
Interface requirements and information exchanges between the ITS project and other planned and existing systems and subsystems; and
Identification of applicable ITS standards.

A number of resources are available to assist agencies with the systems engineering process. One example is a "Systems Engineering Guidebook for ITS" sponsored by the Federal Highway Administration (FTA) and the California Department of

Transportation. In addition, Section 8 of the "Location Referencing Guidebook"[8] contains information to help agencies comply with the FTA National ITS Architecture Policy on Transit Projects, particularly the systems engineering aspects that pertain to spatial data sharing. Strict adherence to systems engineering practices will help accomplish five key activities that significantly impact a project's success[9]:

1. Identify and evaluate alternatives;
2. Manage uncertainty and risk in systems design and implementation;
3. Design quality into systems;
4. Control "life cycle" costs of a project; and
5. Handle program management issues as they arise.

FTA's National ITS Architecture Policy on Transit Projects reinforces the need for collaboration on procurement efforts among key stakeholders such as IT, the business client, other ITS participants, legal and procurement staffs, and regional partners. The Policy also emphasizes that roles and requirements pertaining to the development and/or maintenance of data or systems need to be defined. In addition, procurements of affected transit ITS applications will also require that more attention be directed to standards.

2.2.1.4 Transit Internal Architecture

At the transit agency level, the ITS Architecture should be integrated with the transit agency's Information Technology (IT) Architecture. ITS applications use many of the agency's IT components such as agency core data (e.g., schedule data, bus stop information, operator IDs, spatial data), local area networks (LAN), wide area networks (WAN), database management systems, ad hoc reporting software, servers, and other hardware and software. If significant changes to either the IT and/or ITS systems and infrastructure are not coordinated, system failures or unwanted interference might occur. For example, adding the massive data flows from a new AVL system to an agency's WAN/LAN can cause performance issues if the network capacity is not designed to handle the additional communications load.

Agencies with state-of-the-art strategic planning processes apply a method known as Enterprise Architecture Planning, or EAP,[10] to help improve the success and cost effectiveness of IT and ITS investments. The Federal Chief Information Officers (CIO)

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[8] The full title of the guidebook is "Defining Geographic Locations of Bus Stops, Routes and Other Map Data for ITS, GIS and Operational Efficiencies: Best Practices for Using Geographic Data in Transit: A Location Referencing Guidebook." See Bibliography for Integration.

[9] From "Building Quality Intelligent Transportation Systems Through Systems Engineering." See Bibliography for Integration.

[10] From Steven H. Spewak, Steven C. Hill, Enterprise Architecture Planning: Developing a Blueprint for Data, Applications, and Technology, September 1993.

Council (1998) approved EAP, and the Federal Enterprise Framework was established in 1999 to promote shared development, interoperability, and sharing of information for federal agencies and other government entities.[11] The Office of Management and Budget (OMB) released its *OMB Enterprise Architecture Assessment Framework (December 2005)* to help improve performance of technology investment decision making through the alignment of EAP with management processes including strategic and capital planning and program/project management. The term "enterprise," while understood in the context of the overall transit organization, transcends the established organizational boundaries to include external stakeholders. For example, a transit agency's enterprise IT/ITS architecture may include a data exchange mechanism with an adjacent transit agency or a metropolitan planning organization.

Based on the EAP methodology, business goals and needs should drive the implementation of technology. Therefore, an understanding of the transit business environment is necessary to properly align the integration strategies and technology choices to the business. Elements of the business environment that drive the technology investment include the mission, vision, goals, guiding principles, and critical success factors. Consideration of stakeholders and stakeholder needs influence the development of the goals, objectives and system requirements.

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. EAP becomes a method for defining an organization's current (baseline) systems and technology environment, desired (target) environments, and transition strategy. It is essential for evolving information systems and inserting emerging technologies such as ITS that optimize mission value.

EAP also supports the process of defining architectures and developing blueprints for the use of information in support of the business and the plan for implementing those architectures. It provides the framework to begin the definition of documented and coordinated structures for cross-cutting business needs and design developments, and support collaboration among the divisions for increased efficiency and improved services to the transit customer.

The adoption of explicit standard-oriented policies and guidelines, established in compliance with technology principles, is fundamental to the EAP process.

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[11] From *A Practical Guide to Enterprise Architecture Version 1.0 – Federal Council of Chief Information Officers* (February 2001). See also, https://secure.cio.noaa.gov/hpcc/docita/files/federal_enterprise_arch_framework.pdf.

2.2.2 State of the Art

The implementation of regional ITS architectures, agency IT/ITS architectures, and project architectures has contributed to the success of ITS implementations, the leveraging of transit resources, the minimization of duplication, and offers a greater degree of seamless transit services for customers. The architecture development process has provided a forum for agency staff to share information, learn about collaboration and integration opportunities, and improve planning. The architecture development effort also helps with understanding the driving forces behind business processes, organizational roles, responsibilities, strengths, strategies, issues, and needs. The process is as important as the outcome.

Most regions of the U.S. have now completed regional ITS architectures, and a number of deployment statistics and reports are available to the transit industry.[12] Examples include national summary reports, survey summary reports, metropolitan area reports, and medium city reports. In addition to the USDOT's Web page on deployment reports and statistics, the USDOT has an Examples Web page[13] that provides linkages to examples from existing regional ITS architectures that follow the development process described in the Regional ITS Architecture Guidance Document.[14] Examples are included for the six major steps in developing a regional architecture: Get Started, Gather Data, Define Interfaces, Implementation, Use the Regional Architecture, and Maintain the Regional Architecture.

Below are some examples where benefits have occurred from implementing regional ITS architectures, internal IT/ITS architectures, or project architectures.

- The Metropolitan Transportation Commission (MTC), representing the San Francisco Bay area, has implemented a regional architecture that facilitates the development of integrated, regional ITS applications such as GIS services, Trip Planning support, and others.

- The Iowa DOT has set the stage for the implementation of a statewide Automated Vehicle Locator/Global Positioning System (AVL/GPS) in the Iowa public sector. The DOT serves as the consortium manager for the project and sets contracting standards on behalf of approximately sixteen transit systems in Iowa. The ITS architecture process helped prioritize transportation problems, helped identify

[12] www.itsdeployment.its.dot.gov/download.asp#surveysummary.
[13] Examples from ITS regional architectures are linked at the following Web site: www.ops.fhwa.dot.gov/its_arch_imp/examples.htm.
[14] "Developing, Using, and Maintaining an ITS Architecture for Your Region," prepared by the National ITS Architecture Team, October 12, 2001.

stakeholders in the state with common needs, and assisted with coordinating ITS activities in different regions in the state.[15]

- The Los Angeles County Metropolitan Transportation Authority (LACMTA) has an Arterial ITS Inventory and Architectural Project that is guiding ITS investments. In addition, LACMTA has developed a regional project architecture for its electronic fare collection project, enabling multiple transit agencies in the region to participate at a lower cost and providing customers with a more seamless fare paying experience.

- A comprehensive IT/ITS architecture and strategic planning effort was completed with broad staff participation at Miami-Dade Transit (MDT) to help guide the IT and ITS investments at MDT. The effort helps staff to understand project dependencies and priorities, and identify key stakeholders and opportunities for leveraging investments and other benefits.

2.2.3 Emerging Trends

The South Carolina Department of Transportation (SCDOT) is coordinating a statewide technology infrastructure for paratransit and demand-response transit in both urban and rural areas. Applications will be centrally hosted, and each regional transit authority will access and use applications via its Web browser.

The Town of Chapel Hill in North Carolina is setting the stage for implementing a new portion of its regional architecture. It is planning to implement a real-time passenger information system that potentially can be implemented by other transit agencies in the Triangle Region.

An ITS project architecture was developed for an "Illinois Transit Hub" in the Gary, Chicago, Milwaukee region. The role of the Illinois Transit Hub is to serve as a collection and distribution point for transit ITS data, and to support value added systems such as transfer connection and certain traveler information facilities.

2.2.4 Challenges and Lessons Learned

Several challenges and lessons learned pertaining to the development and use of architectures to integrate ITS technologies were identified. They are summarized below.

1. Although transit agencies send staff to participate in the development of the regional architecture, many transit staff that work on ITS projects are often unaware of the details of the regional architecture.

[15] www.itslessons.its.dot.gov/its/benecost.nsf/DisplayLessonByStateSingle?OpenFormandState=Iowa.

2. In areas where regional travel can occur across a number of metropolitan areas (such as the New York, New Jersey, and Philadelphia areas), some coordination across regional architectures may be needed.
3. Many of the largest integration benefits for transit occur internal to their agency, not just with other regional partners.
4. The National ITS Architecture has added more detail internal to the transit ITS applications to help transit agencies identify and obtain integration benefits.
5. The ITS architecture for a transit agency needs to be closely linked to the transit agency's IT architecture. ITS applications have a high dependency on the agency's IT data model, database management system, network capacity, and other IT components.
6. 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.
7. Key to the successful deployment of ITS technologies is to have the agency's goals drive the information and technology investments. These goals should also be reflected in the various architectures.
8. To ensure long-term benefits to transit agencies and their customers, transit staff needs to develop strategies for sharing data resources and data maintenance activities with external organizations. Furthermore, agencies should *establish formal agreements* on the communications, security, data management, and information exchange requirements for all interfaces and the resources needed to implement those interfaces.
9. The lack of an onboard architecture can be an issue for transit vehicles when ITS components are added to the vehicle. Significant planning and integration is needed to ensure the necessary and efficient flow of data between the onboard ITS components and the back-office environments. Often, the process to ensure the flow of data has fallen between the cracks of the IT organization, the bus procurement group, vehicle maintenance, and engineering. To ensure that this does not happen, multidisciplinary skills and cross-organization coordination are needed for the success of ITS applications with respect to onboard components.
10. Integration of technology cannot occur without the integration of business objectives and policies of the departments and/or agencies that are expected to cooperate in an ITS project.

2.3 Enterprise Data

ITS systems require accurate data to operate effectively. They also typically need to receive and share data with other transit agency information technology (IT) and ITS systems and databases. In a number of implementations, the ITS systems must also share data with legacy systems such as human resource systems. Some ITS systems, such as APC systems, need to manage potential large volumes of ITS information and require methods for data creation, storage, update, maintenance, analysis, and distribution. ITS projects may never operate efficiently and effectively if required data sets are not integrated and maintained properly.

Enterprise data are the set of core data that describe the service provision, operating environment, assets, operations, and maintenance information, and are shared by multiple organizational units and applications throughout the transit agency. Business sub-areas may have their own internal sets of core data. The core data include data sets used by planning, service planning, asset and maintenance management (for automatic vehicle monitoring), fare and ridership, risk management, security, customer information and marketing, and many other areas. Core data may be generated by, or flow through, customer and back-office systems, field systems, or onboard transit revenue and non revenue vehicles. Core data have a life cycle, and exist in different versions over time.

By managing core service and operational data from an integrated, enterprise-wide perspective, a transit agency can more cost effectively realize the benefits of ITS investments, reduce duplicative data maintenance efforts, and avoid potentially embarrassing data inconsistencies that require troubleshooting and resolution efforts. Additional efficiencies can also be realized when disparate service and operational data sets from various parts of an organization and ITS systems are integrated and fused into key performance indicators, and then analyzed over time to support informed decision making. Finally, ITS implementation project delays and cost overruns due to data issues can be minimized or avoided if the agency's implementation plan includes provisions for factoring in the time needed and the project dependencies associated with defining data requirements and data relationships and completing data development.

2.3.1 Technology Description

The technologies that support the development of the enterprise data are relatively straightforward and consist of:

Transit Agency Data: Core data sets that are shared and used by many organizational units within the agency. These data may be maintained over time, flow through several applications, and pass through a life cycle.

Transportation Network: Geographic Information Systems (GIS) data including the street network, landmarks, address attributes, place names, and other geospatial data sets upon which the transit network and applications may be built. GIS data will be discussed in more detail in Section 2.4, GIS.

Database Management System (DBMS), data management, and reporting tools: In additional to a DBMS, there are several data management and reporting tools that will help transform legacy data, clean and aggregate data for warehousing, and develop complex reports from distributed databases throughout the organization.

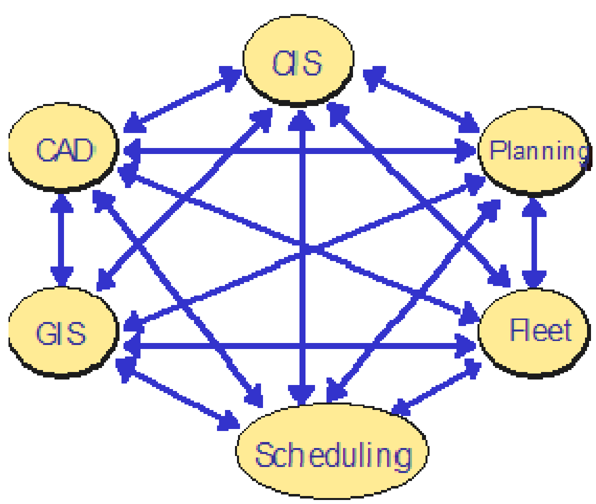
Distributed Logical Data Model: Similar to a framework or plan, the logical data model describes the data, its format, semantics, and relationship to other data concepts. The logical data model is one of the key technologies that provides a roadmap for building and evolving the enterprise data infrastructure.

Data Policies and Procedures: Policies and procedures are used for accessing, creating, describing, updating, deleting, and providing resources to maintain data sets across an organization. Data policies and procedures are typically developed by a data committee that represents the range of business areas in transit. This group develops the standards and specifications for data that must be followed enterprise-wide.

2.3.1.1 Application-centric and Progression to Data-centric

Most transit agencies and other organizations are moving away from a "stovepiped" architecture where most applications were developed independently for a single business area. This stovepiped architecture results in a haphazard approach to sharing data and implementing systems, which is technically referred to as an "application-centric" approach. This approach can become chaotic and is also referred to as a "Spaghetti Model of Interfaces" because of its multiple, customized data connections (see Figure 4).

Figure 4 "Spaghetti Model of Interfaces"



When using an application-centric approach, much of the data sharing and combining occurs through the use of custom data interfaces between applications. Often, the application wraps a proprietary "skin" around the internal data produced by the application, making the data inaccessible to outside queries from off-the-shelf data query tools that are not provided by the vendor. The inherent complexity and proprietary nature of these applications make it difficult to find reliable and current information quickly.

The application-centric approach to data access also makes it difficult to combine data from different systems into more complex, integrated reports. To support user needs, IT staff have developed separate ad hoc reporting tools for each application, which only allows them to view selected profiles of the internal application data set.

In summary, an application-centric architecture is vulnerable to problems associated with:

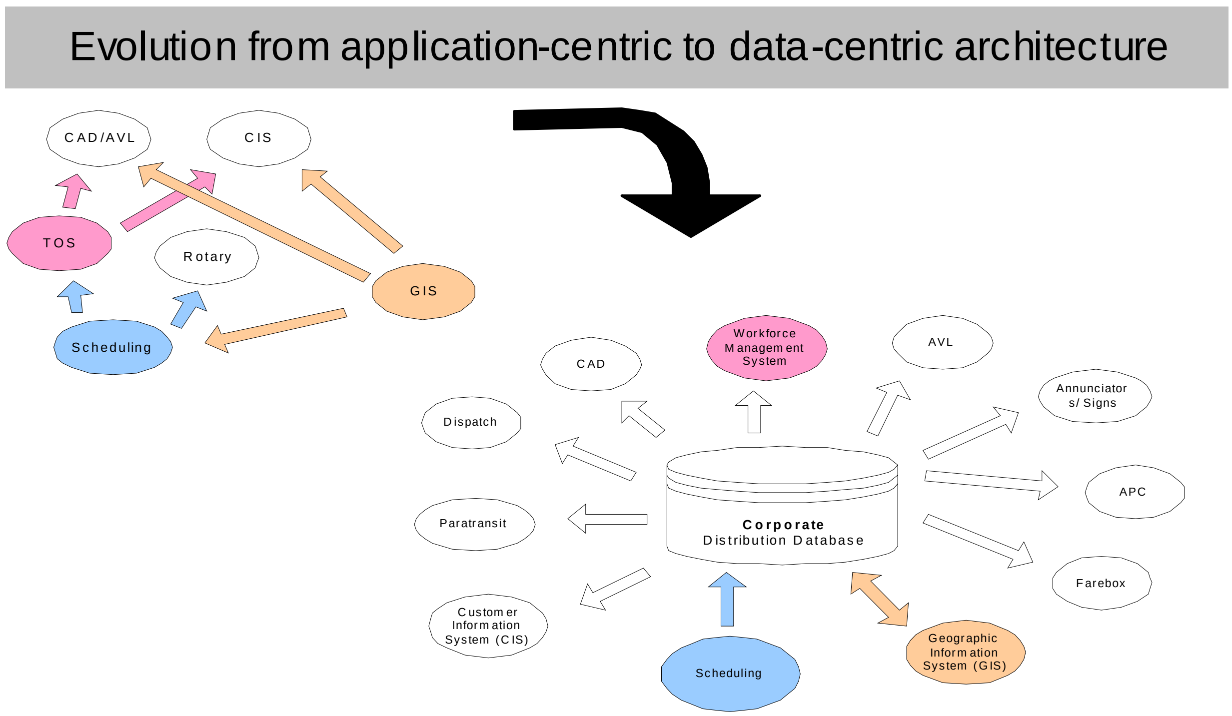
- Separate databases for each application that rely on customer interfaces to access data;
- Data redundancy, data duplication, or missing data;
- Multiple interfaces resulting in high maintenance costs;
- Challenging or missing application integration and data sharing;
- Lack of business process view for applications and data; and
- Difficulty in obtaining data and information for decision making under ad hoc circumstances, or when information from multiple systems needs to be combined.

In order to successfully meet planned and future ITS application data requirements, agencies will need an unambiguous transfer of information between systems and databases, along with assurances that data generated throughout the agency are consistent, accurate, and complete. For example, a future Customer Information/Trip Planning system requires data integrated from multiple sources to operate. These sources include base map, bus stop, route, and schedule data. Another example of integrated data is that used for planning. Combining APC data with the base map, route alignments, and fare information allows planners to more easily assess ridership. To operate efficiently, these ITS systems must have the ability to:

- Share spatial information;
- Contain updated base maps and attribute information;
- Contain updated transit feature data (bus stops and timepoints);
- Integrate transit feature data with geo spatial features for analysis; and
- Transfer real-time data for application transactions.

Many agencies see the benefit of moving from an application-centric approach toward a "data-centric" or information enterprise approach to managing applications and data. The reason for this shift lies with the overlapping data requirements of ITS systems and the potential for data creation and maintenance efficiencies. As illustrated in Figure 5, the data-centric approach replaces the application-centric approach to overcome the disadvantages associated with traditional "stovepipe" implementations. Placing a database at the center of ITS applications allows for faster and more accurate business processes, and provides more meaningful and consistent transit information.

Figure 5 Corporate Data Evolution from Application-Centric to Data-Centric Approach[16]



For effective support of transit information needs, enterprise data in transit needs to have the key technology elements in place, including:

- Core data sets that are shared;
- A transportation network;
- Commonly shared database management and reporting tools to minimize multiple learning curves and maintenance needs;
- A distributed logical data model; and
- Well communicated policies and procedures.

Despite the advantages, many agencies are having difficulty moving toward the data-centric approach. Funding to support this type of relatively hidden data infrastructure is critical. Just as buses and trains need a good infrastructure to traverse, so does data

[16] Image originally developed in 2001 by Michael Berman, King County Metro.

need a flexible and robust infrastructure to make information and systems access quicker, easier, and more accurate. In addition, business processes must support the elimination of the traditional "stovepiped" (i.e., departmental focus) systems approach. A critical success factor is business ownership of the data and supporting applications where those with the greatest stake in the data's accuracy and currency guarantee its quality. These business processes must be driven by a set of agency data policies and standards such as a data dictionary, logical data model, exchange formats, data owners and custodians, as well as security and access. Doing so ensures a consistent set of internal data standards across the organization.

2.3.2 State of the Art

Data development, integration, and management considered to be state-of-the-art generally include elements such as the use of:

- Agency-wide or regional data dictionaries;
- Data standards;
- Attention to regional, agency, and project architectures;
- Integration strategies;
- Publicized and followed policies and procedures;
- A standard graphical user interface for accessing the data and conducting ad hoc reporting; and
- A commitment to funding the development and maintenance of an enterprise-wide and/or regional data infrastructure.

2.3.2.1 King County Metro (KCM) Transit Enterprise Database (TED)[17]

In the early 1990s, Seattle Metro Transit, now called King County Metro (KCM), realized a need to collect core schedule, facilities, and GIS data for the purpose of creating an integrated, commonly described data set to be distributed to downstream applications. This Distribution Data Base (DDB) became a central authoritative source for integrated core data sets throughout the agency. To get started, Seattle Metro bought the conceptual data model from another agency. By doing so the agency was able to populate fields they could use immediately, and modify or migrate to other fields as needed. The DDB enabled significant reporting and analysis capabilities. It also enabled the development of key applications such as the GIS Tool Box, an application for planners and others who need to create maps and analyze scheduling and routing data.

The data model remained relatively stable and unchanged through the years until about five years ago when agency staff set out to develop an enterprise transit data model that more precisely met KCM's changing business processes. The new data model was partitioned by subject area to improve its scalability, distribute ownership of key sets of

[17] From a discussion with Dan Overgaard and Bob Syslo-Seel, King County Metro Transit.

data, and shield one business area model change from impacting another. Procedures were put in place to track downstream application interface needs and upstream application interface changes. In addition, KCM expanded coverage of the model to include employees, financial accounting, and projects. The new data architecture, known as the Transit Enterprise Database (TED), is composed of several databases distributed and linked throughout the organization.

Early in the development process, KCM's staff realized that certain data policies and procedures were needed to deploy an enterprise data system. Some of the more important steps taken by the agency to accomplish this include:

- Creation of an enterprise data dictionary with common names, conventions, and descriptions adopted across the organization;
- Assignment of ownership of relevant data to individuals who care the most about the accuracy of the data. For some bus stop data, this might be the customer information service representative who deals with customer complaints when the service data is incorrect; and
- Creation of new database access and security tools that allow more than one person to update a general category of data. For example, types of bus stop signage might be updated by someone in Customer Information and the type of shelter at a bus stop might be updated by someone in the facilities department.

2.3.2.2 TriMet Enterprise Database

TriMet, Portland, OR, began with a data model and central data repository that dates back to the late 1980s. The model evolved from a single table to the point where the database is now the central repository where data processing occurs and data is distributed to downstream applications as needed. According to one Tri-Met manager, evolving the data model to accommodate new applications is much like "performing an environmental impact study"[18] in that each new application requires integration with the existing database design. When new applications provide additional data, the model may be changed to accommodate a one-way feed into the enterprise database to support the integration processing, storage, and distribution of those data.

TriMet's enterprise data approach enables a wide range of benefits, including:

- Sharing data and data maintenance efforts in the region;
- Easy to maintain access methods of core data by ITS applications, such as schedules, routes, and bus stop information;
- A seamless linking for the user of spatial and nonspatial data;
- The ability to easily do ad hoc data analyses and mapping; and

[18] From correspondence with Bibiana McHugh, GIS Manager at Tri-Met.

Allowing both desktop and Web access to data by TriMet employees, regional partners, and transit customers. Examples of ITS data that are extensively accessed, analyzed, and mapped at TriMet include their APC and AVL data.

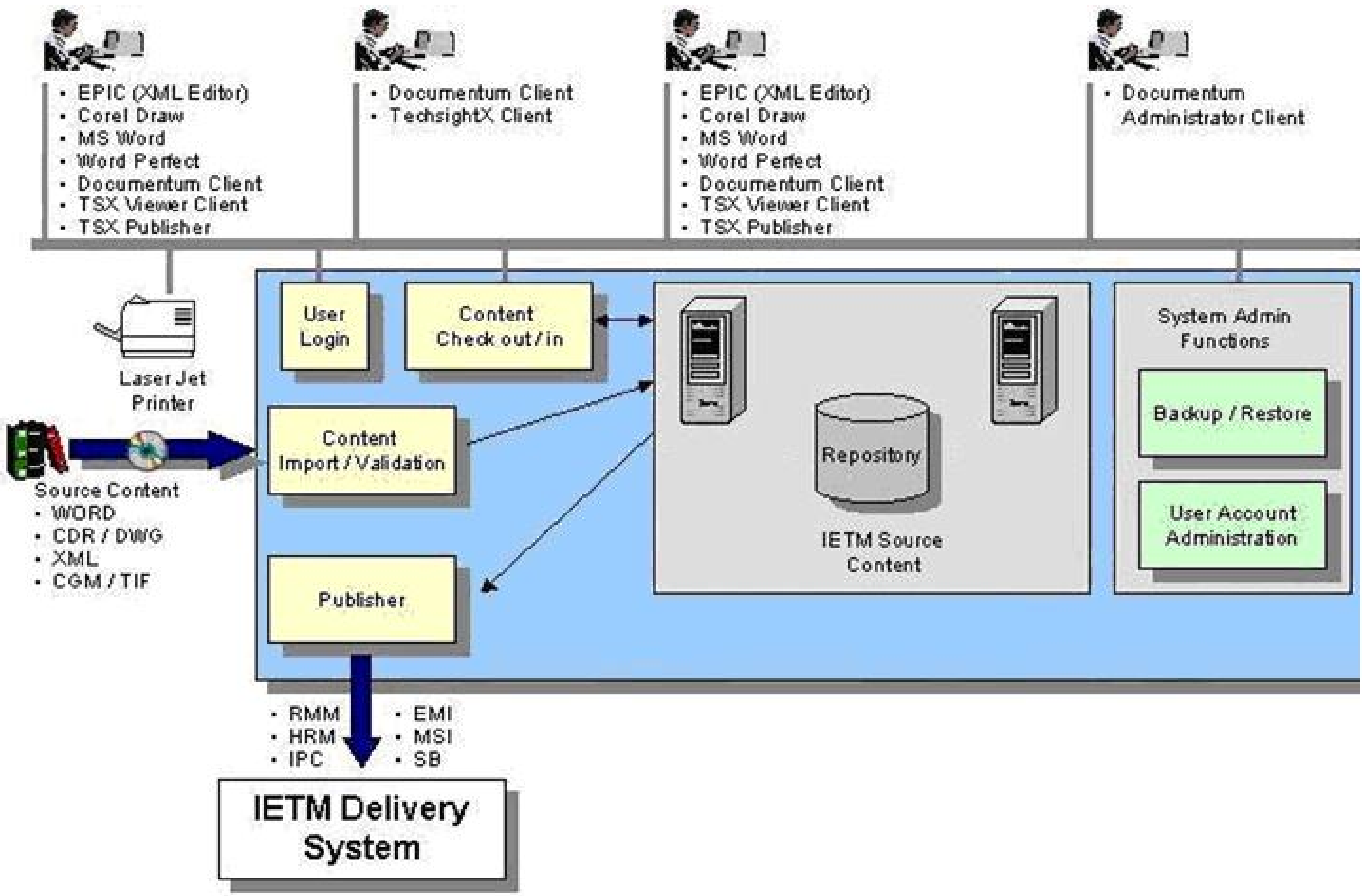
2.3.2.3 WMATA Interactive Electronic Technical Manuals (IETM)[19]

New data approaches are now being included in some state-of-the-art transit applications to enterprise data. Broadly defined content, such as documents, technical manuals, other media, and service and performance information can now be linked together and managed through a workflow and the data's life cycle. The tool making this possible is referred to as an interactive electronic technical manual (IETM). WMATA recently deployed an IETM to integrate their maintenance management system with related maintenance manuals, integrated parts catalogs, warranty information, electronic equipment specifications, and other critical documents.

By integrating additional information technologies using off-the-shelf standards and tools, the IETM enables WMATA to link related information and to reuse, revise, distribute, and control informational content in different forms. The current implementation supports information pertaining to the agency's heavy rail car rehabilitation content. Future functionality may expand to all of WMATA's maintenance areas. Figure 6 illustrates the functional architecture of the WMATA IETM.

[19] From a discussion and presentation prepared by Peter Meenehan, WMATA.

Figure 6 Functional Architecture of WMATA Interactive Electronic Technical Manuals (IETM)



Military studies have demonstrated that IETM technology[20] can:

- Reduce false alarms, fault isolation times, maintenance time, and false removal rates;
- Increase percentage of successful fault isolation;
- Promote greater effectiveness of inexperienced technicians;
- Improve personnel and equipment safety;
- Reduce turnaround time for reporting and correcting technical manual discrepancies; and
- Reduce technician time spent completing maintenance forms.

By using IETM technology, maintenance personnel can view maintenance information related to specific vehicle identification numbers. The electronic nature of the IETMs allows instant updates and corrections, thereby providing the most accurate and up-to-date information to mechanics to enhance safety and promote equipment reliability.

2.3.2.4 NJ Transit Data Warehouse

A data warehouse is a specialized database that transforms and loads data from multiple sources. In the extraction and transformation process, data are "cleaned" and aggregated into a layer that may be associated with a specific time period. NJ Transit developed a data warehouse for APC applications and other onboard electronic subsystem and engine monitoring functions. During this automated process, the system performs over 70 quality checks on the data before they are loaded into the warehouse. The quality check process applies business rules to approximate missing data, correct errors, and flag problems it cannot solve. The warehouse now generates several performance trending reports on bus ridership and stop inventory quality.

2.3.3 Emerging Trends

2.3.3.1 Regional Transit Stop Inventory

Many regions developing regional transit coordination centers, such as the "Transit Hub" in the Gary, Chicago, Milwaukee region, the "Transit Schedule Data Exchange Architecture" (TSDEA) in downstate New York, and across Florida, are realizing the value of coordinating the exchange of consistent schedule and transit network data among transit providers. Exchange of transit service information supports many multiple agency coordination activities such as scheduling transfers among modes and providers, informing riders of public transportation stops, and providing trip planning services to customers. These regional centers realize the need to establish regional data standards to support the unambiguous transfer of service data among transit providers. One of the most difficult activities encountered by these agencies is matching stops

[20] Presentation from WMATA.

among the various agencies. When the stops enter the regional inventory they contain different formats for identifiers, they may be mapped to different base maps or use different referencing systems, they vary in attribution, and have other differences. For example, a stop may appear multiple times using different identifiers, address styles, and location references. That stop is then submitted by the owning agency followed by all the other agencies using the stop. The process to reconcile and clean the data is an enormous undertaking. Several projects including those involving the Metro DC transit agencies, Center for Urban Transportation Research (CUTR) representing the state of Florida, Oregon and Washington DOTs, and the New York State Department of Transportation (NYSDOT) are now undergoing the development of regional transit stop inventories, and developing standards and tools to support their maintenance.

2.3.4 Challenges and Lessons Learned

There is no easy solution for developing an enterprise data approach. The key factor that emerges from the various state-of-the-art deployments is that there is someone who pursues the migration with vision and dogged determination. While small enterprise systems may be developed as individual initiatives within an organization, larger successes require senior management support and long- term commitment because the deployment affects change throughout the organization.

Key factors in making an enterprise data system successful over the long term include:

- Senior management support and commitment to information management as a business strategy;
- Development of an overall plan and migration approach to creating, maintaining, and evolving the enterprise data architecture;
- Development of key data policies and procedures that are widely accepted by major stakeholders and business areas. These policies and procedures must be supported at the procurement level. Data policies may include:
  - New applications to develop a one-way feed into the enterprise database (i.e., core data are provided to new applications only from an interface from the enterprise database);
  - Data descriptions and semantics used throughout the organization conform to an enterprise data dictionary;
  - Data development and acquisition;
  - Data access, security, and ownership rules;
  - Data policy committee; and
  - Internal standards for archiving and describing data sets (metadata);
- Understanding the need to accommodate change into the process because technology is evolving at a fast rate;

Developing a clear set of requirements and reports that meet business needs and challenges before an application is developed. Make sure that the information infrastructure can support those reporting requirements;

Understanding that a trained Database Administrator (DBA) is essential to every successful Enterprise Data System. Larger organizations may also have a systems analyst and data architecture/analyst. The database administrator is needed to address the day-to-day operations, while the data analyst supports and evolves the data and database structure. The system analyst manages and develops programs that require information from the database; and

Speaking to transit professionals at other organizations who have deployed similar applications and learning from their challenges.

2.4 Geographic Information Systems (GIS)

Spatial data, such as the geographic location of bus stops, routes, transit facilities, and the regional street network, are critical for the efficient operation of transit. Transit management needs to know where their operators, vehicles, facilities, and customers are located to best plan and operate their systems. GIS provides the tools for creating, managing, analyzing, and displaying spatial data, and for supporting ITS applications. Spatial data and some GIS functionality are also critical for supporting ITS applications such as AVL, APC, and Itinerary Planning systems, as well as others.

GIS data and applications must become essential elements of an agency's information technology and ITS architectures to ensure an effective and efficient information technology infrastructure. Spatial data should be considered one of the most important subsets of the transit agency's enterprise data described in section 2.3 above. Many of the best practices developed for regular data management also pertain to spatial data. This section will discuss spatial data in additional detail because of its close links to GIS systems.

Integration of both GIS and spatial data efforts, within a transit agency or region, can provide some of the biggest integration cost-saving benefits in ITS. With so many ITS applications in transit using a street network base map and transit features such as stops and routes, having only one database in which to maintain a particular data set is a big benefit in terms of lower costs, more efficient use of staff time, and better data consistency. Having only one GIS system saves licensing costs and reduces training requirements. Benefits can also include more efficient service delivery, better quality services, more accurate customer information, and improved integration between modes and service providers.

2.4.1 Technology Description

GIS is not an off-the-shelf application, but a complex information system comprised of key components. In addition to staff trained in GIS skills, GIS consists of the following five architectural components:

- **Data**: A wide range of spatial data can be supported by a GIS, such as points, lines, polygons (e.g., zip code area, census blocks, fare zones, etc.), and remote sensing data.
- **Databases**: A data repository is needed for the spatial data and its associated features. Database management functions, some specialized to spatial data, are also needed. A GIS supports the association of descriptive information about an object with its geographic location. The GIS also facilitates the combining of different types of geographic data and map layers, such as waterways, transit routes, streets, and landmarks. Another important function of the database is to make its data contents available to users and other information systems.
- **Software**: GIS software provides the tools to create, update, and manage spatial data and associated nonspatial data, such as the bus stop amenities associated with a bus stop location. A GIS also provides a wide range of spatial analysis and mapping tools.
- **Applications**: Since GIS is a broadly used tool across many industries, industry-specific GIS applications need to be developed.
- **Hardware**: GIS analyses and spatial data management often require a relatively large amount of computing "horsepower." More disk space and memory are needed, as are faster network speeds, larger display devices, and powerful output devices for mapping displays.

Linked with the GIS are the following four broad categories of spatial data management processes:

- Data creation or collection, which may involve a variety of methods such as map digitizing, geocoding, or GPS-based data collection efforts.
- Maintenance and management of spatial data, including data security and possible linkages with an enterprise database management system (DBMS).
- Geoprocessing, such as buffering, geocoding, spatial analysis and queries, projections of data, querying for an optimal route between and origin and a destination, and generation of distance calculations.
- Data output and distribution to end users, IT and ITS business systems, and to external agencies.

2.4.2 State of the Art

A large percentage of transit agencies are using GIS according to TRB's Transit Cooperative Research Program (TCRP) Synthesis 55 document published in 2004 and titled "Geographic Information Systems Applications in Transit." These results are based on the 2003 Transit GIS Survey,[21] which is currently being updated. The Synthesis 55 report examines the value of GIS to transit agencies and summarizes the experiences of a variety of transit agencies with information provided from a variety of different sized agencies. The Synthesis documents current practices, effective applications, and includes several case studies and challenges.

State-of-the-art advances in GIS have occurred in several areas, with many regional and enterprise-wide GIS systems implemented by transit agencies. Web-based maps and GIS applications are faster to develop and faster to use, plus their features and appearances have also improved. A growing number of agencies are incorporating multiple views of the spatial data, such as showing the street network in line form, in remotely sensed images, or with the two combined. In addition, LIDAR (LIght Detection And Ranging) data, which provides spatial data with *x-y-z* coordinates, is starting to be used in a few transit applications.

A closer linkage is now possible between GIS and database management systems (DBMS). Some spatial data can now be stored in some commercial DBMS. As a result, GIS is better able to support ITS applications and data maintenance efforts. Finally, new GIS-based applications that support incident tracking or management, such as security incident tracking systems, can help agencies better understand event patterns and, as a result, better deploy resources.

TriMet has produced some of the most progressive GIS applications in the U.S. Some of the important features of the agency's GIS environment include:

- A single base map for efficient data maintenance and high data accuracy;
- A commitment to systems integration and linkages to an enterprise-wide relational database;
- A well-designed Configuration Management Plan for Base Map Updates in a regional area;
- A Location Referencing Authority Table[22] that facilitates location referencing and transit GIS tools that can be reused in a range of applications; and
- A GIS working group that is part of the Information Technology team helps it to adhere to IT and ITS standards, better share IT resources and purchasing power, have an agency-wide business perspective, and better integrate GIS with the IT infrastructure.

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[21] According to the 2003 Transit GIS Survey, 74% of the 77 transit agencies that responded are using GIS. The survey results can be found at www.e-transit.org/survey/20022003/.

[22] See Section 6.4.5, Building a Location Table, in the guidebook, "Defining Geographic Locations of Bus Stops, Routes and Other Map Data for ITS, GIS and Operational Efficiencies: Best Practices for Using Geographic Data in Transit: A Location Referencing Guidebook."

As a result, TriMet has been able to support a wide range of GIS and ITS applications such as AVL, APC, Work Order Tracking, Customer Complaints, Trip Planning, and real-time Transit Tracker. TriMet's interactive transit Web maps are attractive, helpful, and easy to use. Figure 7 shows the query options for TriMet's interactive Web map. Figure 8 shows a ridership analysis example, at the bus stop level,[23] from the agency's Bus Dispatch System (BDS) Mapper application, which analyzes historical data gathered by TriMet's AVL and APC systems.

The BDS Mapper application can also display ridership analysis using varying thickness of line width to show ridership levels between stops, between time points, and at the route pattern level.

[23] The size of dot in the figure reflects the relative number of boardings at that bus stop.

Figure 7 Example from TriMet's Interactive Transit Map

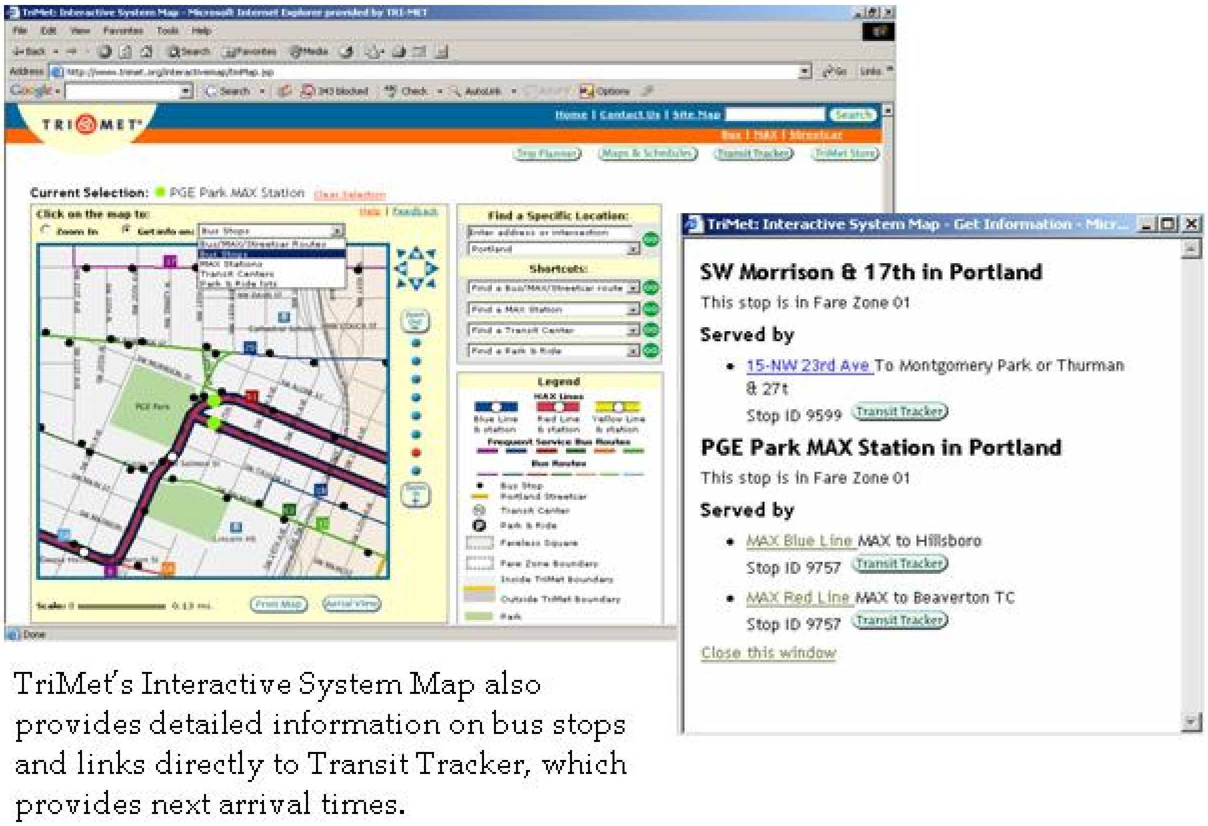
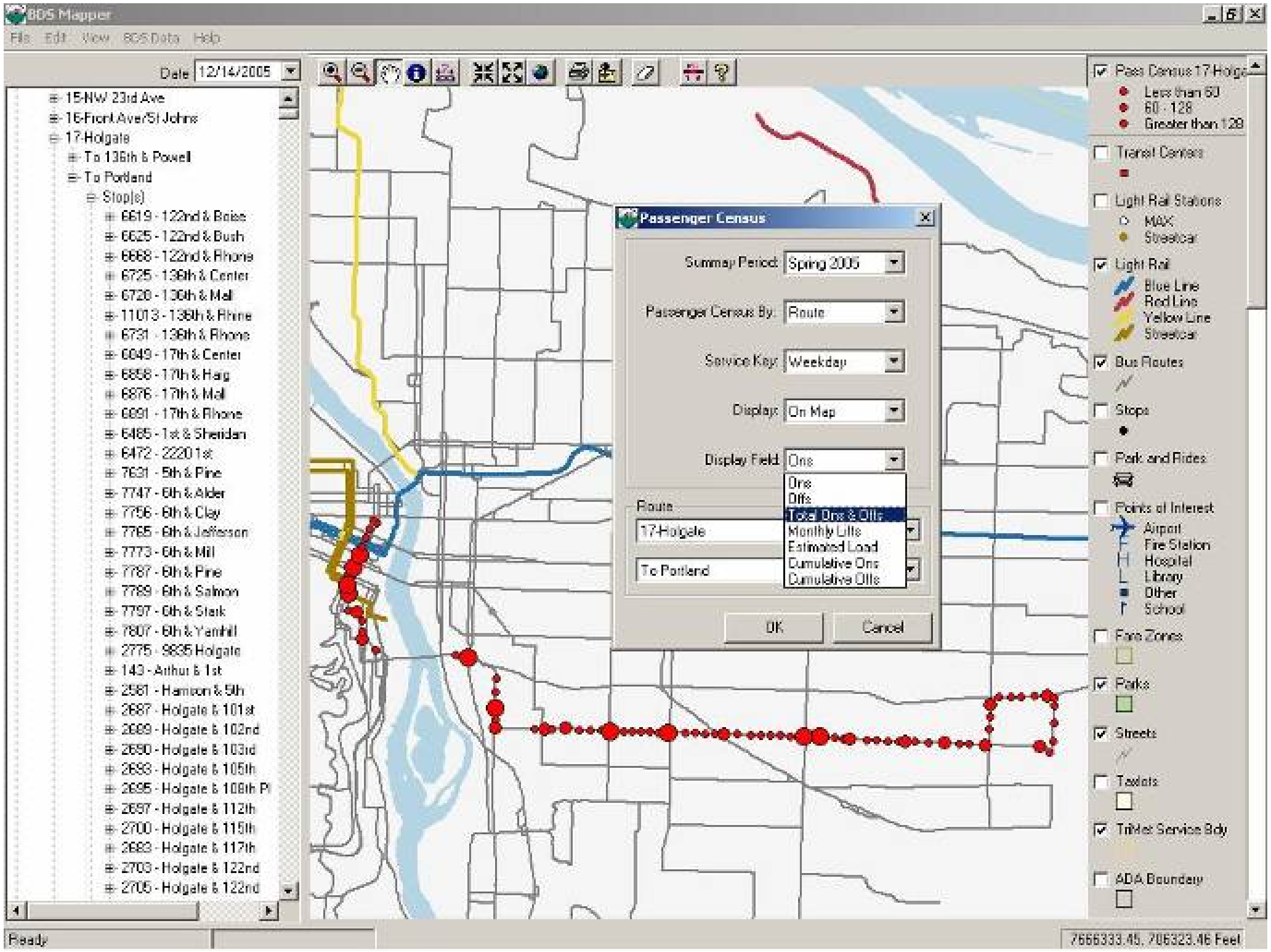


Figure 8 Ridership Analysis Example from TriMet's Bus Dispatch System Mapper



The Metropolitan Transportation Commission (MTC) in the San Francisco Bay area has a regional database that includes spatial data. Having a regional, enterprise approach to transit GIS allows MTC to facilitate ITS applications such as regional trip planning as well as other planning and customer information applications. MTC's regional approach to GIS also supports integration across transit modes and carriers.

The location of Cape Cod Regional Transit Authority buses is shown on its Web-based Cape Cod AVL Mapper. The project was implemented by the GeoGraphics Laboratory at Bridgewater State College in Massachusetts.[24]

The prototype system was designed to be affordable by smaller agencies. The hardware is commercial-off-the-shelf (COTS), while the software is freeware (e.g., Linux) or resides in the public domain. The system provides AVL Web-mapping with one-second refresh rates. It also provides the estimated time of arrival of each vehicle at principal bus stops. Bus location can be accessed by customers from their desktop computers, campus kiosks, wireless laptop/PDA at bus stops, or while onboard the bus.

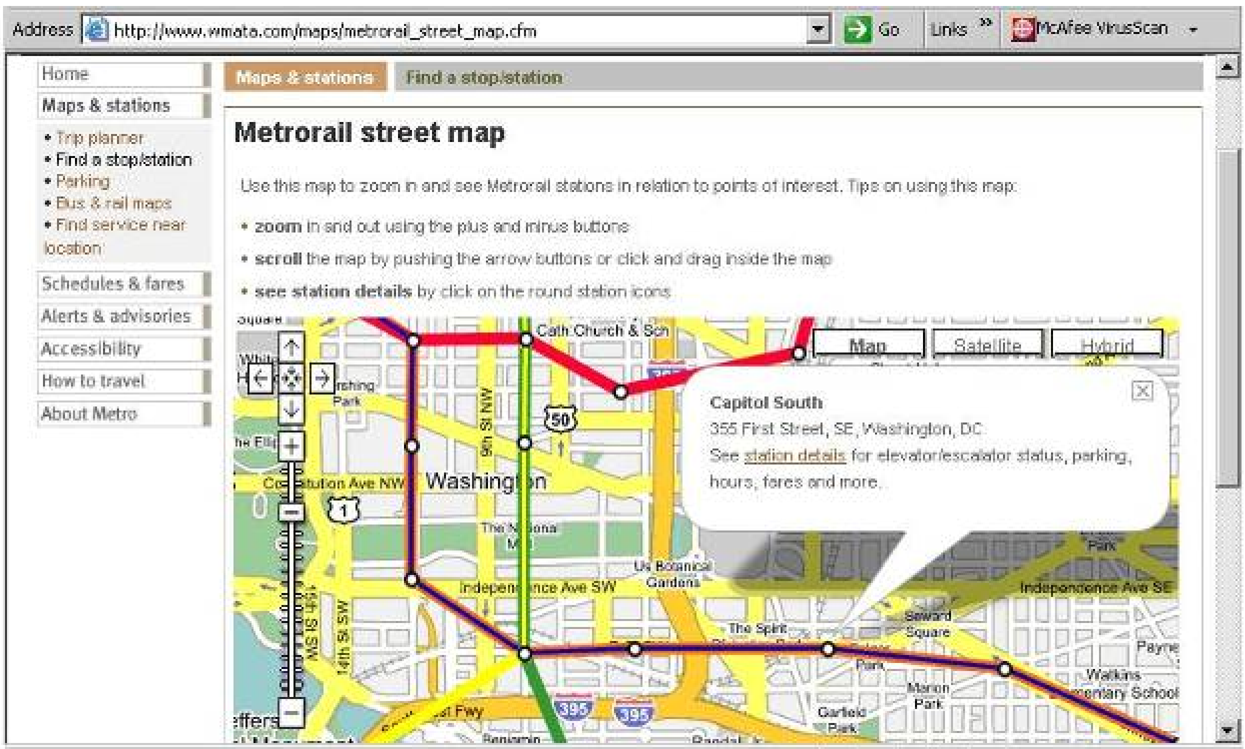
The Utah Transit Authority has taken an enterprise-wide approach to GIS, allowing it to have more accurate and efficient GIS applications and data maintenance efforts.

"Estops," an online GIS-based tool that maintains transit bus stop inventory data, was developed by the San Diego Association of Governments (SANDAG) for transit operators in the San Diego region. The tool, the first of its kind, allows agencies to maintain their own stop inventory data in a centralized database by using a secured Web site. Now that GIS and DBMS technology advances are available, SANDAG would like to upgrade the system to have only one underlying, integrated database and faster mapping capabilities. The region has benefited for years from a single regional bus stop inventory that features unique ID numbers for commonly shared stops, and unified protocols for changing a stop and notifying other affected agencies.

WMATA has implemented on the Web a very clear and easy to use Metrorail Street Map[25] shown in Figure 9 that allows the user to zoom, scroll, and see station details. The application was implemented using an application program interface (API), which was made available to developers of map applications for beta testing.

[24] http://geolab.bridgew.edu/home/.
[25] www.wmata.com/maps/metrorail_street_map.cfm.

Figure 9 Interactive Metrorail Map from WMATA



King County Metro Transit (KCM) has also taken an enterprise-wide approach to GIS. This integrated approach has core spatial data for the region and tools in a GIS Toolbox that are used by a wide variety of ITS applications. Examples of KCM's state-of-the-art GIS-based applications include the GIS Toolbox, a Security Tracking System, and a GIS-based Stop Information System for the creation, maintenance, and display of bus stop and route stop sequence information. Figure 10 shows an output from KCM's Stop Information System.

KCM has also recently implemented TNET (Transportation Network),[26] which provides the King County region with a feature-rich, accurate base map that is maintainable by the various cities and jurisdictions in that region. Only recently has the technological infrastructure advanced to a level that allows the introduction of sharing data maintenance of a centrally stored geodatabase by widely dispersed multiple users. Participants in the TNET Consortium will realize benefits that include:

Reduced data costs;

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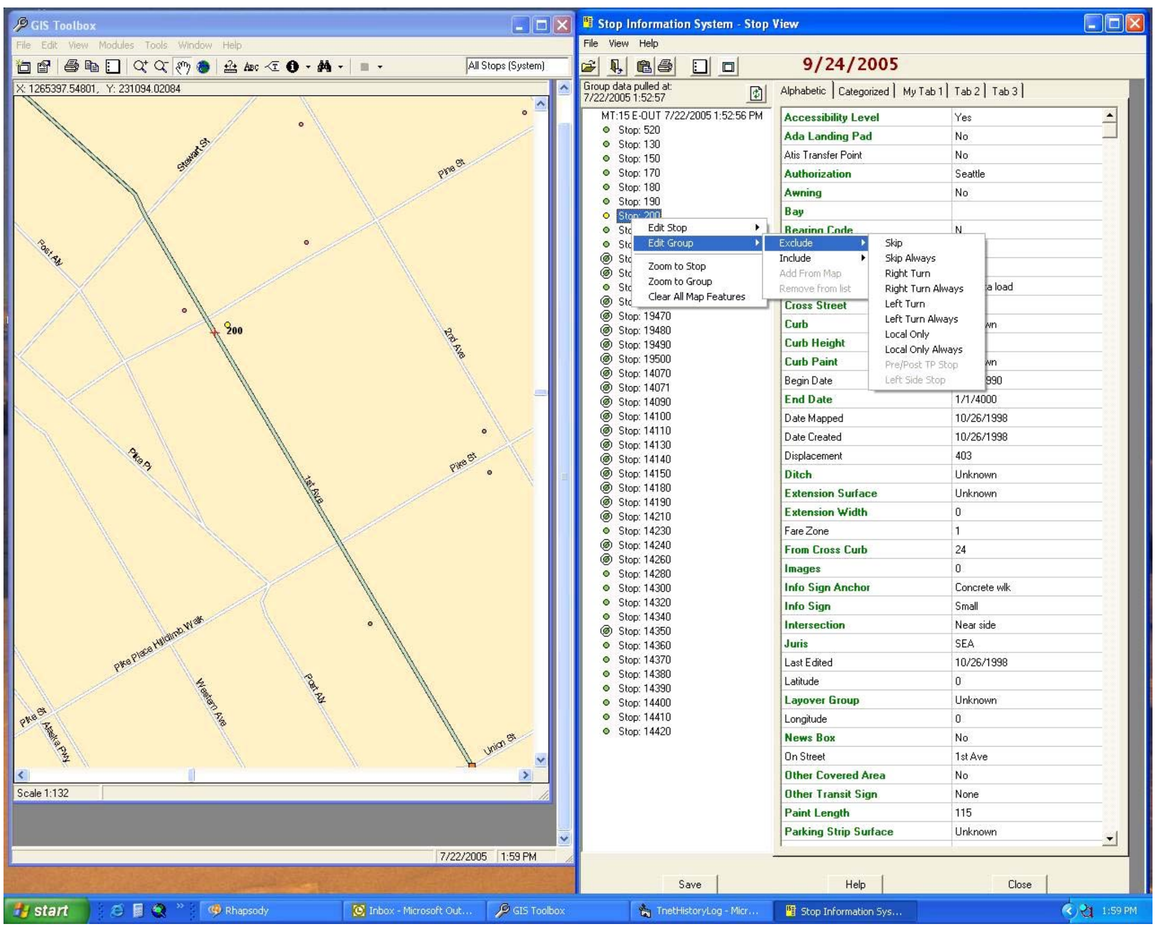
[26] www.metrokc.gov/gis/Projects/TNET/tnet_consortium.htm.

Improved data quality;
Minimized data conflicts;
Improved participant operations;
Leveraged technology investments; and
Improved support for cross-jurisdictional decision making.

KCM also conducted an innovative analysis that combined GIS and LIDAR data (location and altitude data) to determine the best site options for a radio repeater.

Figure 10 Example from KCM's Stop Information System



2.4.3 Emerging Examples

- Google, the search-engine company, is currently beta testing a GIS-based Transit Trip Planner on the Web at www.google.com/transit, which provides powerful viewing options of the spatial data and transit data provided by TriMet in Portland, Oregon.
- New tools have allowed a number of other individuals and organizations to provide alternative spatial layouts of transit schedule and trip planning data by "data scraping" transit Web sites and displaying the transit data using new or Open Source Software tools. These efforts pose some issues for transit agencies because sometimes the alternative efforts present the data in a more attractive manner than the transit agency is able to present on its own. However, the "data scraping" approach is not robust and these supplemental Web sites, which can be popular with the public, may provide inaccurate data if the transit agency changes the Web site that is being "scraped."

2.4.3.1 Emerging Spatial Information Standards

There are several spatial data, GIS, ITS, and transit standards emerging to support integration and interoperability. Examples of these standards include:

Geographic Markup Language (GML), which is a specialization eXtensible Markup Language (XML);
Transit Communications Interface Profile (TCIP);
The U.S. government's Geospatial One-Stop;[27]
Location Referencing Method Specification (LRMS);[28] and
Other ITS standards.

This list of useful standards and tools is expected to grow in the future and benefit transit. The Open Geospatial Consortium, Inc. (OGC) is a nonprofit, international, voluntary consensus standards organization that is leading the development of standards for geospatial and location-based services.

Listed below are brief excerpts on some of the key emerging spatial-related standards from the TCIP Concept of Operations.[29] Additional information on these standards is included in Section 2.6, Transit ITS Standards.

[27] It is part of an intergovernmental project managed by the Department of the Interior in support of the President's Initiative for E-government. See the Web site at www.geo-one-stop.gov.
[28] Summary information on the standard is available at www.standards.its.dot.gov/StdsSummary.asp?ID=419.
[29] "Transit Communications Interface Profiles. Draft Standard Version 2.7.1" Section 5.10, Concept of Operations for the Spatial Data Management Process, APTA, 2005.

4. **TCIP:** TCIP spatial data frames and data elements are used within TCIP messages in all TCIP business areas. TCIP references and incorporates elements of other spatial standards such as LRMS. Although there are many spatial feature transfers that are not within the scope of TCIP, there are other related and consistent industry standards that can work in conjunction with TCIP to provide the interfaces necessary for a transit agency to implement a robust spatial data management process.

5. **Geographic Markup Language (GML**): This standard, available from the Open Geospatial Consortium (OGC), describes geospatial feature relationships and formats that may be used to compose a transportation network and/or location references associated with spatial features (e.g., bus stops, route segment paths, etc.). It contains geospatial descriptions for a variety of layers including hydrology, cadastral, and transportation. It is used in a wide variety of environments and industries, and includes support by most GIS products.

6. **GeoSpatial One Stop (GOS)**: Defines the representation of geospatial data, their definition, format, and relationship, including feature sets for various geospatial domains including hydrology, transportation (roads, rail, air, waterways, and transit). GOS describes data type definitions for vehicle and operator assignments, trips, routes, transfer points, amenities, and more. The model may be used to create an XML Schema using GML or TCIP/LRMS.[30] The GOS program includes the specification of Web services for publishing, searching, and viewing geospatial feature sets.

7. **Location Referencing Method Specification (LRMS):** The LRMS standard describes the data elements and frames necessary to describe location references using a variety of geographical, addresses, and linear reference methods as it relates to a transportation network. Also based on XML, LRMS describes more types of linear and attribute (i.e., address) referencing methods for transportation than GML, however, the relationship among the spatial features are assumed from a given transportation network. LRMS is used in TCIP primarily to define data elements and frames that provide many of the spatial data concepts that are used throughout TCIP and other ITS Standards. LRMS spatial data concepts support a variety of representations for geo-spatial data including address-based, latitude-longitude, and state plane coordinates.

[30] If the appropriate associations are made between the features and data elements.

2.4.4 Challenges and Lessons Learned

2.4.4.1 Barriers to Sharing Spatial Data

A variety of barriers have been identified that limit or prohibit agencies from fully realizing the benefits of a GIS. Many of these barriers limit the efficient development, management, integration, exchange, and use of spatial location information, which compromises the support of business needs that depend on spatial data. These barriers can occur both within a transit agency and between organizations in a region when data sharing or systems integration is required. The barriers may be due to technical and/or organizational issues. Examples of these barriers are provided below.

- Multiple databases and applications can introduce barriers due to:
  - Inconsistent naming conventions;
  - Different transit data models;
  - Embedded GIS-like functionality with different data representations;
  - Differences in data source quality;
  - Transformations and translations;
  - Poor documentation (metadata); and
  - Use of different location referencing systems.

1. Insufficient awareness or knowledge of standards, existing tools, and available utilities.
2. Weaknesses in systems specifications and the quality of Request for Proposals (RFPs).
3. Insufficient definition and execution of operational and data maintenance responsibilities. This may also include poor maintenance agreements with commercial map vendors that result in all of transit's street and route updates being erased when a new release is issued.

A number of these barriers can prevent the unambiguous referencing of transit feature location attributes. A significant barrier to success is how the location of spatial data is characterized or referenced. When locations are not clearly referenced, they cannot be accurately transformed from one location referencing method to another, potentially resulting in unsuccessful data sharing, mapping errors, and other analysis problems.

2.4.4.2 Lessons Learned

The GIS-related lessons learned that are identified in this section support successful transit decision making and operations by improving GIS and spatial data usage in analyses, maps, customer information, and ITS applications. In additional to using good GIS technology practices, the effective enterprise-wide use of GIS tools and spatial data requires the successful integration of traditional management practices with good systems engineering practices. GIS practitioners voiced a strong need for good management support to achieve an integrated, efficient approach to GIS and the support of other ITS applications.

Some of the more significant lessons learned and best practices that were identified are included below. The 2005 Guidebook on Best Practices for Using Geographic Data in Transit[31] identifies additional best practices, and elaborates on them from the perspectives of general management, GIS practitioners, and ITS project managers.

- A deliberate degree of standardization is required across the enterprise to successfully share information. Users must share a common vocabulary including data meaning and format. To fully realize the benefit, the data must be stored and accessed similarly.
- Create an enterprise-wide GIS approach, and define standard access methods to share transit feature data and other spatial data. Centralize the methods as stored procedures or middleware.
- Adopt a single, enterprise-wide base map to maintain and propagate it to different applications for further customization as needed; evaluate the options for acquiring a base map that meets transit business needs across the agency.
- Identify and ensure the quality and accessibility of "core transit spatial data."
- Define a corporate transit feature dictionary and define an enterprise data model, store and manage the transit features centrally, and establish procedures for collecting and updating data.
- Understand data and application dependencies.
- Use unique ID numbers for core transit features; do not reuse or delete ID numbers during the life of a feature inventory.
- Define an "Addressing Format" for your agency. A number of options exist, such as the format used by the U.S. Postal Service or the Census Bureau. The most important best practice is to be consistent across all applications within an agency.
- Develop a spatial data maintenance program and synchronize the maintenance schedules for the various applications that use spatial data from an enterprise-wide perspective.
- Have metadata, which is data about data, including documentation on data quality. In the metadata, document the quality of the spatial dataset, the data collection procedures, and the identification and access methods. In addition, support application integration using an enterprise-wide repository of integration metadata. Develop the repository incrementally as each project is developed.

[31] Titled "Defining Geographic Locations of Bus Stops, Routes and Other Map Data for ITS, GIS and Operational Efficiencies: Best Practices for Using Geographic Data in Transit: A Location Referencing Guidebook."

Develop a "location reference authority" such as a location table to support transit spatial feature portability and the storing of transit feature data. Include several key location referencing methods in the feature description or in the location table.

Consider sharing data development and maintenance efforts with regional partners.

Use a systems engineering approach in developing and integrating applications, and for the definition of stakeholders and their requirements.

Use standards. If not available from standards organizations, develop and communicate internal standards.

Understand the intellectual property restrictions on the access and use of commercial data or data stored in commercial applications.

Ensure sufficient enterprise data resources (e.g., database administration staff, data owners, budgeting for updates and training).

2.5 Communications

In the past, communications may have been implemented as part of the deployment of an individual application. Today, the communications environment is seen as a foundation for supporting a wide range of agency business processes, new transit service opportunities, and new methods for delivering these services. Communication strategies are now being planned in ways that do not limit options for future network components or services, either within the agency or for reaching beyond into the surrounding community. A solid communications foundation backed by good strategies is essential for integrating data, systems, and business processes.

In regions where transit customers might benefit from the exchange of information among transportation modes and various public sector stakeholders, state-of-the-art (SOA) transit operators are carefully coupling agency objectives with external efforts to improve regional communications and access to information. With agency efforts becoming more closely aligned with regional efforts, better communication linkages are also occurring in the areas of public safety and emergency response.

To support increasing demands for transparent access to data, state-of-the-art transit agencies manage the development of the communications environment as a continuous process to keep it aligned with agency business strategies and requirements, emerging standards, plans for future growth, and changing technology. Such a managed strategy is especially important in environments where the funding available in any given year may be adequate only for partial implementation, one "building block" at a time.

2.5.1 Technology Description

Communications systems provide data and/or voice communications for transit planning, maintenance, operations, and incident management, as well as coordination with transportation providers and public safety organizations beyond the transit community. These systems support mobile, onboard, and fixed-end equipment (i.e., equipment housed at an agency's management center). Communications systems technologies include:

- Analog Radio (voice);
- Analog radio data modems;
- Digital Radio (voice and data);
- Dedicated Short-Range Communications (DSRC);
- Broadband Wireless Networks;
- Wireless Local Area Networks (W-LAN) (for automated data download/ upload);
- Mesh Networks (special case of short-range communications in which multiple nodes are dynamically linked to form a self-configuring, self-healing wireless network);
- Text paging (for transmission of data to remote signage, etc.);
- Satellite Communications (typically for backup communications);
- Cellular Telephone (for primary or backup communications);
- Cellular Data Communications (for remote data collection such as AVL);
- Commercial Telecommunications (network backbones);
- Internet; and
- Intranet/Extranet.

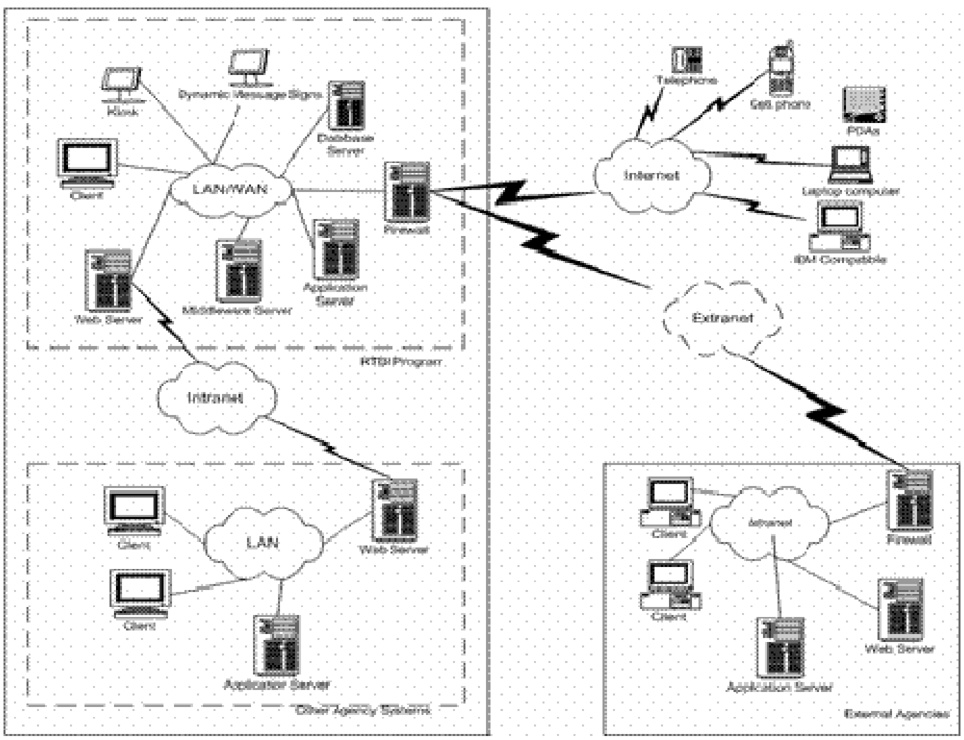
Transit communications extend well beyond transit-specific installations and encompass a great many technologies, environments, and applications, many of which involve ubiquitous telecommunications technologies typically installed and maintained by others such as the commercial telephone infrastructure and the Internet.

Transit communications technologies must either be a part of, or effectively linked with information technology (IT) communication networks. The use of open (i.e., non-proprietary) IT standards for networking has become increasingly critical for support of agencies' growing demands for transparent access to data. SOA agencies carefully consider the impact of ITS applications on the overall IT communications infrastructure, with special considerations as to how the agency's existing internal local-area-networks (LAN), wireless, and other aspects of its shared communications infrastructure will be linked and managed to wide-area-network (WAN) capabilities. This is particularly critical in cases where information will be disseminated to a community that extends beyond transit.

Secure WAN access is very important. WAN administration and security management become critical success factors whenever an agency extends its services to support information flows to and from users outside its firewalls. WANs utilize Internet protocols that require additional security features such as firewall upgrades. They also require higher bandwidths to support increased traffic, perhaps using Virtual Private Networks (VPN). These enhanced features may be implemented in partnership with other regional stakeholders for maximum security, performance, and cost-effectiveness.

IT networks comprise a myriad of complex technologies, many of which are beyond the scope of this report. However, Figure 11 from WMATA provides a conceptual diagram showing basic interconnects among the various networks and computing systems.

Figure 11 WMATA Conceptual Communications Network



As shown in this figure, the Extranet communications network[32] (i.e., the T1/ISDN communication "cloud") is positioned to ensure the exchange of data among public sector agencies, and may become a regional initiative. Data from transit vehicles would also be communicated to a transit agency's network. Appendix A of this report

[32] LAN or WAN infrastructures, using Internet protocols, are often referred to as Intranet and Extranet, respectively.

provides transitional, best practice, and emerging IT network strategies relative to the OSI 7498-1 Network Reference Model.

For the purposes of this report, focus has specifically been placed on communications technologies that are likely to be deployed by a transit agency for communication to and from a transit vehicle, or between field devices and their associated transit management center. These transit-specific ITS communications applications have been divided into three major categories:

Wide Area Wireless Communications;
Short-Range Wireless Communications; and
Corridor and Metropolitan Area Communications.

2.5.1.1 Wide Area Communications

Wide area wireless technologies support data and voice communications between transit management centers and transit vehicles, support vehicles, customer information devices, and transit police services. The most common of these wide area technologies is dedicated voice radio, followed by cellular voice and data services, and satellite communications.

Many of the existing voice radio systems were deployed in a centrally controlled configuration where users transmit a "request to talk" code over a dedicated network control channel, and are then automatically assigned to one of a number of other voice radio channels (frequencies) for the duration of the actual voice transmission. By allocating the available voice channels among the users who need them most at a given point in time, this technology, called "trunking," provides better frequency utilization than configurations that permanently assign specific frequencies to specific groups of vehicles.

"Trunked" analog radio technologies represented the state-of-the-art for many years starting in the 1970s and extending through the mid-late 1990s. More recently, however, as digital radio has matured, transit agencies are replacing their trunked analog technologies with entirely digital solutions.

Analog voice radio operates by varying the amplitude (i.e., amplitude modulation, or "AM") or frequency (i.e., frequency modulation, or "FM") of a radio signal in response to an audio input. Whether that audio input is silent or loud, the analog signal consumes the same bandwidth (i.e., the entire channel).

Digital voice radio operates in a different fashion. Digital voice radio encodes and compresses a voice conversation into a compact electronic data stream (ones and zeros) that is then transmitted in a series of tiny bursts, and then reassembled by the receiver.

If the audio input is silent, no data are sent. Because of this, and because digital radio allows data from more than one conversation to be carried simultaneously on a single channel, this technology offers far greater frequency utilization efficiency than the trunked analog systems popular during the last century. The quality of digital voice communications can vary depending on many factors such as quality of service control and channel bandwidth. However, since the digital voice message is transmitted in a form that is less susceptible to interference and fluctuations in audio volume, digital radio often also offers greater voice clarity than analog.

Additionally, digital radio offers the ability to communicate not only to and from vehicles, but between the transit management center and its associated passenger information devices in the field as well. Some passenger information systems now being deployed utilize this technology exclusively when communicating to displays in the field. When coupled with a solar cell for electrical power, these easily installed devices can communicate with the local infrastructure without requiring any physical wiring in the field.

Digital radio may be the current technology of choice for agency-owned-and-operated wide area wireless communications. However, it is not the only solution available. Many smaller agencies, especially rural agencies with large service areas but few vehicles, have found it more economical to simply go to their local cellular carrier. A variety of cellular solutions have been successfully deployed, sometimes coupled with satellite communications as a backup to fill any gaps in local cellular coverage. One advantage of such hybrid systems is the ability to call upon the relatively limitless bandwidth capability of the commercial provider to support occasional extraordinary data needs, such as the transmission of live digital video for incident management without impacting routine fleet management communications. A downside to cellular solutions sometimes occurs when the commercial system becomes overloaded and unavailable during a crisis.

2.5.1.2 Short-Range Communications: WiFi, WiMAX, and DSRC/WAVE

Off the shelf technologies for short-range wireless communication are currently being deployed in communities and at transit agencies across the U.S. The trend over the last few years has been to deploy Wireless Ethernet or IEEE 802.11 [hereafter called 802.11] to download vehicle condition and event data, and upload configuration files needed by the vehicle's onboard systems. Recent deployments are also seeing 802.11 serving as the vehicle area network (VAN) onboard the bus, or used in conjunction with mobile access routers to provide mobile "hot spots" for riders to access the Internet while in route.

Wireless standards are based on the wireless Ethernet / IEEE 802.11 or IEEE 802.16 family of standards. Wireless Fidelity (Wi-Fi) uses IEEE 802.11, WiMAX uses IEEE 802.16, while DSRC primarily uses 802.11, but may use 802.16 to link back to the conventional telecommunications infrastructure. Each approach is described in the sections below. Table 3, found at the end of this section summarizes the benefits and challenges of each technology.

Transit agencies are implementing off-the-shelf Wi-Fi to the emerging standards identified above. Although the differences among the various technologies are summarized in Table 3 below, this section will only describe two emerging wireless technologies:

WiMAX
DSRC/WAVE

2.5.1.2.1 WiMAX

The IEEE 802.16 WiMAX Air Interface Standard is an emerging specification for fixed broadband wireless access systems employing a point-to-multipoint (PMP) architecture.

The WiMAX standard for mobile applications is based on IEEE 802.16e, which is still in the phase where users are offering comments. While a dedicated frequency has not yet been assigned by the Federal Communications Commission (FCC), commercial product vendors are anxious for its release and are already developing applications, base stations, and terminals. The standard is expected to be finalized mid-2006.

WiMAX is expected to work in the licensed 2.5 GHz and 3.5 GHz, or the unlicensed 5.8 GHz frequency. The bandwidth is adjustable from between 1.5 to 2.5 MHz to support efficiencies in segmenting channels to serve different types of platforms and facilitate transmission over longer ranges.

The City of Seattle[33] has demonstrated a pre-standard WiMAX application at 4.9 GHz. At that frequency, the agency estimated that a base station would need to cover an area of about a mile radius, with 50 to 55 base stations needed to blanket the city for coverage.

Commercial manufacturers are already gearing up for production. Intel expects that the WiMAX chips will be sold at about $300 apiece within a year of the standard's completion. In the early implementation stages, before costs drop, it is estimated that base stations will cost $10,000 to $15,000, with customer premises equipment (CPE) selling for about $500.

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[33] Information provided by City of Seattle.

2.5.1.2.2 WiMAX versus Wi-Fi

WiMAX and Wi-Fi are different technologies that are not incompatible. Although they may function together to provide short-range and long-haul functionality, they require different equipment. Because they operate at different frequencies, however, they may be used concurrently to enhance the services offered (e.g., Wi-Fi may patch or augment WiMAX coverage). Furthermore, WiMAX may also be used to link the Wi-Fi access points (whether they are standard or mesh) in lieu of a physical backbone connection. A summary of Wi-Fi and WiMAX technologies is provided in Table 3.

Table 3 Summary of Wi-Fi and WiMAX Technologies

Standard	Frequency	Benefits	Challenges
Standard Wi-Fi IEEE 802.11b		Off the shelf 802.11b products Initial investment is cost effective for corridor deployments Support range of up to 1 mile (with improved technology) Radio transfer of 5-10 Mbps. Practical data throughput of about 5 Mbps or less	Bridges may not be covered by non-licensing rules Additional questions related to omni-directional intersection coverage remain
Wi-Fi IEEE 802.11 Mesh Network [802.11a, b, and g]		Off the shelf 802.11 products Initial investment is cost effective for small deployments Adaptive network path to base station Supports range from device to Access Point of between 4 feet to just under a mile Channel of about 15 MHz	Larger subscriber base is needed to cover larger areas Shared bandwidth Latency Proprietary implementation Standardized Mesh Network isn't available until 802.11s (2007) Standardized Quality of Service management isn't available until 802.11e (2006)
802.11a	5 GHz	Higher speed (54 Mbps)	Proprietary implementation
802.11b	2.4 GHz		Slower Speed (11 Mbps)
802.11g	2.4 GHz	Higher speed (54 Mbps) Ability to handle interference Interoperability with 802.11b	

Standard	Frequency	Benefits	Challenges
WiMAX IEEE 802.16e and 802.16-2004		Delay Spread Line-of-Sight (LOS) not necessary Improved QOS Flexible channel bandwidth (may be between 1.5 and 20 MHz) for greater efficiencies in serving different customer needs and segmenting into multiple channels Supports range of greater than a mile Flexible channel size	Multi-path interference Mobile WiMAX approved as standard December 2005; testing standards due in late 2006
802.16e 802.16-2004	2.5 GHz* 3.5 GHz* 5.8 GHz	Mobile and fixed	
DSRC/WAVE [IEEE 1609 Working Group]		Robust Fast Localized transmissions from vehicle–to-vehicle (V-V) and roadside-to-vehicle (R-V) to serve many public safety and private commercial applications Latency minimization Authorization Prioritization Supports Vehicle speed (up to 120 mph) Communication range (up to 1,000 meters for special vehicles; nominal is 300 meters) System latency (< 50 ms) Data rate (default is 6 Mbps; up to 27 Mbps) Single transaction size (up to 20K bytes) 10 MHz channels	Unknown at this time
IEEE	1609.1	WAVE Resource Manager	
IEEE	1609.2	5.9 GHz ITS radio service security	
IEEE	1609.3	WAVE networking services	
IEEE	1609.4	WAVE multichannel operations	
IEEE	802.11p	5.9 GHz wireless LAN medium access control and physical layer based on chipset from 802.11a	

* Requires a license to operate

2.5.1.2.3 DSRC and WAVE

A number of complementary standards are being developed specifically to support short-range vehicle-to-roadside, roadside-to-vehicle, and vehicle-to-vehicle communications. Of particular interest are Dedicated Short-Range Communications (DSRC) and a new family of standards termed Wireless Access in Vehicular

Environments (WAVE).[34] Both are being developed by the Institute of Electrical and Electronics Engineers (IEEE).

The Dedicated Short-Range Communications (DSRC) effort, originally sponsored by the U.S. DOT and later migrated to the IEEE Standard Development Organization, is a derivative of the IEEE 802.11 family of standards. DSRC technology uses industry-standard IEEE 802.11a components, thereby leveraging a wider market for the base technology. The 802.11 version will be called 802.11p. Table 4 summarizes the performance parameters of the technology.

The proposed standards upon which DSRC will be based are expected to be promulgated by mid-2006 to 2007. Equipment based on the proposed standard was demonstrated at the 2005 ITS World Congress in San Francisco, and a consortium of toll operators is currently working on prototype equipment and demonstration programs. According to the DSRC Interoperability Consortium, the technology is about five years from deployment.

Table 4 DSRC 5.9 GHz Prototype Attributes

Frequency Range	5.855 - 5.925 MHz
Data Rate	6 - 27 Mbps
Channel Bandwidth	10 MHz
Power Output	18 dBm
Transmit Frequency Stability	10 ppm
Channel Switch Time	<= 2 us
Transmit Spectral Mask	FCC Class C
Safety Message Protocol Support	IEEE 1609 WAVE Short Message
Internet Protocol Support	IPv6
External Interface	Ethernet (RJ-45)
Enclosure Size	4.20" x 7.15" x 1.35" (106.7 x 181.6 x 34.3 mm)
Operating and Storage Temperatures	-10 to +70 deg C
Input Power	+12 VDC @ <3.25 Watts

The DSRC standard was designed to transmit messages in a short period of time. In doing so, the standard attempts to achieve the following performance levels:

Low latency;

[34] "DSRC Technology and the DSRC Industry Consortium (DIC) Prototype Team." SIRIT Technologies, January 28, 2005. 8 pp.

Short to medium range;
High data rate; and
Directional and omnidirectional frequency capability.

Based on the FCC-assigned frequency and bandwidth 5.9 MHz band (specifically 5.850 to 5.925 MHz), the standard will support:

10 channels;
Middle channel is a control channel established to listen to announcements (for two-way exchange the channel will announce where the reply will broadcast);
Two public safety channels in upper portion of the frequency band;
Lower channels are medium powered channels that are shared among all uses (vehicle to vehicle and roadside to vehicle) for commercial applications such as map updates and large files;
Lowest channel will have the highest availability and lowest delay, for emergency situations such as crash avoidance; and
Highest channel contains a power level consistent with traffic signal priority (TSP) and intersection collision avoidance technology applications.

The DSRC Task Group is developing the IEEE 802.11p standard, which addresses the wireless signal (physical layer) and access control. The associated network and data layers of the interface protocol will be addressed by IEEE 1609 (the WAVE family of standards: WAVE Management, Channel Management, and Resource Manager). Security standards are being developed under IEEE 1609.2.

A decision point in the development process will be in 2008 when the federal government is expected to meet with automakers to decide on whether to go forward and fund a nationwide deployment of the technology in consumer vehicles and the associated roadside infrastructure.

2.5.1.3 Corridor and Metropolitan Area Communications: Mesh Networks

Early metropolitan area networks required installation of a relatively high number of wireless access points (hot spots) throughout the area to be served. Mesh networks take this concept to the next level. Each device in the field itself becomes a relay point for other devices to connect through. The mobile devices themselves work together to create a seamless, continuously reconfigurable grid of high-speed network nodes reaching out as far as their density allows. This is a new technology that is just now beginning to be deployed in pilot projects nationwide. Given sufficient device density and an adequate number of ground-based "hot spots," it offers bandwidth suitable for electronic messaging, mobile Internet, and even real-time video applications.

Based on the established Wi-Fi standards, a mesh Wi-Fi network is a special variation on the 802.11 network that can be continuously built and configured on the fly. In a mesh network, any device outfitted with a wireless card and special software may operate as a wireless access point, router, or end user in a network.[35] The network is adaptive, finding alternate communications paths in real time when a node goes down, is out of range, or is overloaded. The network operates smoothly only when there is a sufficient density of devices that act as nodes, and communications may "hop" from one node to another until they reach a wired backbone.

Wi-Fi signals may extend from about 100 feet to nearly a mile depending on the type of antenna used at the access point (e.g., a high-gain directional antenna may be used to provide a long but narrow coverage area, while a less directional antenna installation can be used to provide a wider but shorter coverage area).

IEEE 802.11s is an emerging standard now under development to improve interoperability of mesh networks in the mobile environment. The standard is expected to be approved in 2007. Lacking an accepted standard, current mesh deployments are based on proprietary solutions.

2.5.2 State of the Art

State-of-the-art ITS communications for transit are currently distinguished by such features as:

- Seamless interoperability between multiple dissimilar radio systems through intelligent integration on the back end;
- Portable or mobile backup facilities suitable for rapid deployment for event, incident, or emergency management, or in case of failure of primary components;
- Reduction of required radio channels through increased use of electronic messaging in lieu of voice communications;
- Intelligent failover, with ability to switch between cellular and satellite if necessary to ensure critical communications;
- Support for use of separate technologies for voice and data, if desired; and
- Wireless data communications not just between management center and vehicles, but between management center and passenger information signs as well.

State-of-the-art deployment examples include:

New Jersey Transit Corporation (NJ TRANSIT), Newark, NJ

Characteristics include:

[35] Walker, Jonathan, "Wi-Fi Mesh Networks: The Path to Mobile Ad Hoc," www.wi-fitechnology.com/Wi-Fi_Reports_and_Papers/Introduction_to_Wi-Fi_Mesh_Networks.html.

Self contained, pre-positioned mobile command posts suitable for routine operations as well as incident, emergency, and event management, with support for bus, rail, and police radio, land-line, cellular, and satellite voice and data communications.

Utah Transit Authority, Salt Lake City, UT
Characteristics include:
Integration with public safety.

Concho Valley Rural Transit District, San Angelo, TX
Characteristics include:
Rural transit system application;
Cellular/satellite integration;
16,000 square mile service area; and
31 vehicles.

Los Angeles County Metropolitan Transportation Authority (LACMTA), Los Angeles, CA
Characteristics include:
Digital radio; and
2,450 vehicles.

2.5.3 Emerging Trends

2.5.3.1 Refarming

Recent rules promulgated by the Federal Communications Commission (FCC) will reallocate much of the radio frequency spectrum over the next several years. Among other considerations, this "refarming" of the radio spectrum will force some agencies into a more modern radio infrastructure that supports closer channel spacing than had been previously available on some older radio equipment.

2.5.3.2 Cellular Digital Packet Data (CDPD)

CDPD services are being phased out in most parts of the U.S. As a result, agencies using this technology for mobile data transmission should already be planning with their cellular providers for migration to the next generation of mobile data services.

2.5.3.3 APCO P25

A new standard for public safety digital radio, promulgated by the Association of Public Safety Communication Officials (APCO), was successfully implemented in a multivendor interoperability demonstration back in 1995. Since then, interoperable radio equipment conforming to the standard, named "P25," has been implemented by a variety of transit agencies and public safety organizations in over 50 countries worldwide. The standard is expected to be particularly attractive to operators seeking interagency interoperability and multivendor interchangeability of components within a small to mid-sized service area. The standard may also be applicable to larger statewide and regional operations as well.

2.5.3.4 Others

Another innovative approach to wide area communications, originally developed to improve frequency utilization and reduce communications costs for medium-sized operators in Europe, is beginning to surface in the U.S. The Port Authority of New York and New Jersey, in conjunction with NJ TRANSIT, is conducting a pilot test of an AVL system that does not involve polling. The system promises reliable arrival time prediction accurate to within less than one minute. The pilot project, which is expected to be complete by the end of 2006, will evaluate reliability of communications, accuracy of arrival time prediction, timeliness of passenger information, system scalability, capital and maintenance costs, and opportunities for system integration. Key characteristics of the technology include:

- Single data channel;
- Intelligent mobile subsystem;
- Exception-based location reporting;
- Variable reporting frequency based on distance from next stop where expected bus arrival time must be delivered;
- One base station for every 200 vehicles;
- Vehicles dynamically manage output power to minimum required for reliable communications;
- Primary operator communications is via mobile data terminal
- Separate radio for voice communications; and
- 30% fewer voice channels required as compared to voice only

2.5.3.5 Wireless Internet

Several transit agencies are conducting demonstrations of wireless Internet access for passengers onboard buses. For example:

- King County Metro is demonstrating and testing wireless Internet access on 30 buses. Commercial cell phone carrier infrastructure is being used to communicate data to/from the bus WiFi "hot spot" (i.e., wireless access point for connecting to the Internet).

- Community Transit, based in Snohomish County, WA, implemented a pilot program in fall 2005 to provide wireless Internet access using cell phone carrier infrastructure on some of its longer commuter routes.

ABQ RIDE in Albuquerque, NM is providing wireless Internet access on its 15-mile-long Bus Rapid Transit (BRT) route called Rapid Ride. The wireless system has mobile access routers on 12 buses. The routers receive the wireless signal from line-of-sight repeater antennas mounted on traffic signal cross-members, and then transmit the signal to the bus. The system is currently supported by a T-1 line[36] and approximately 83 repeater antennas along the transit corridor that are approximately ½ to 1½ miles apart. Because it is a line-of-sight system, a change in elevation or route direction may require an additional repeater antenna to continue the propagation of the signal. The system allows for an Internet "hot spot" on the vehicle, but not along the roadside. ABQ RIDE is exploring the possibility of sending security video data from the bus over the wireless connection under certain circumstances. The use of a T-1 line allows the data transmission to be segmented with a Virtual Private Network into multiple purposes with different levels of access and security. The system was selected in part because it has relatively low ongoing operating costs.

The Brockton Area Transit (BAT) Authority on Cape Cod, MA, is prototyping a proof-of-concept demonstration of an *e-transit village* at Bridgewater State College, which includes using a wireless local area network infrastructure (WLAN) based on IEEE 802.11b for both Internet and fleet management (vehicle location) communications. The project team is working on how to better maintain a connection when moving between WiFi locations.

The Cedar Rapids, IA, transit department, known as "Five Seasons Parking and Transportation" (FSTP), began implementing mobile broadband wireless on a key portion of their transit routes in September 2005. The system uses mobile mesh technology that is high speed, self-forming, and self-healing. The system allows wireless connection to the Internet and the city's data network. One of the goals of the project was to increase the safety of riders and transit employees by implementing video surveillance cameras that can be integrated with the transit vehicle's global positioning system (GPS). As a result, the video can be remotely monitored with vehicle location information available to the viewer. Additional benefits include the availability of wireless Internet access for passengers and the capability to send streaming video to the vehicle along with schedule information, rider alerts, and advertising.[37]

[36] A T-1 line is a dedicated phone line supporting data rates of 1.544 Mbits per second and that has 24 individual channels, each of which can be configured to carry voice or data.
[37] *City Buses Pick Up Wireless Broadband in Cedar Rapids*, Broadband Wireless Exchange Magazine, September 14, 2005, www.bbwexchange.com/publications/page1387-2994932.asp.

2.5.3.6 IEEE 802.11-based Transit Signal Priority; Wireless Networks in Lieu of Inground Communications Infrastructure

Using off the shelf products, the Los Angeles County METRO[38] demonstrated a traffic signal priority (TSP) implementation with the use of a continuous, end-to-end Wi-Fi network consisting of multiple Wi-Fi bridges. This wireless TSP implementation was deployed over 40 intersections along 3 jurisdictions (connecting to 3 different traffic signal control systems). It was based on the IEEE 802.11b protocol. The bridging technology provided coverage up to three quarters of a mile through the use of directional antennae mounted on a pole or mast arm.

Some of METRO's key performance issues include:

- Typical bus travel speeds were from 15 to 35 mph. The system was observed to work at speeds up to 40-45 mph;
- Power fluctuations were a problem until power conditioning devices were deployed;
- Terminal network devices were required to connect controllers to Wi-Fi network;
- Only a one-way transmission was implemented (e.g., bus only sends information to controller);
- The access points/bridges were connected through the existing network twisted pair;
- The approximate cost for each intersection was $12,000, with the onboard portion costing approximately an equivalent sum on a per bus basis;
- Limited bandwidth was needed due to small size of message (uses minimal bandwidth); and
- Directional antennae were used for bridging, which focused coverage on narrow road network alignment; the coverage was not tested on intersections with intersecting bus priority traffic.

2.5.3.7 Data Transmission over Conventional Analog Radio

Data Modem (**Mo**dulate/**dem**odulate) technology allowing electronic data messages to be transmitted via conventional analog radio was introduced over 40 years ago, and has been included in many of the larger transit radio installations ever since. In a new twist on an old technology, a low-cost solution for wireless data communications between a transit vehicle, the transit management center, and bus stop signs was prototyped and tested in a California effort known as the EDAPTS (efficient deployment of advanced public transportation systems) project. The California Department of Transportation teamed with the City of San Luis Obispo (SLO) Transit and California Polytechnic State University to implement the EDAPTS research project at SLO Transit. One of the goals of the project was to make ITS more affordable for smaller transit agencies. One aspect

[38] Information for this section was provided by LAC METRO staff.

of the project was to "piggyback" the digital data on the standard analog voice radio system using low cost, commercially available parts and modules. This approach may represent an attractive near-term option for smaller transit operators with significant unused channel capacity on an existing radio system.

In the EDAPTS project, a data modem was added to the analog radio channel. When the bus left a stop it transmitted a "leaving the stop" message to the central communications center. The center then used a text pager to send a text message about the bus' expected arrival time to solar powered "Smart Transit Signs" located at the next bus stop. Issues associated with the project included latency in the pager technology and the need to disable the data modem's retransmit feature to preserve voice communications capacity required for transit operations. The next phase of the project will develop performance specifications and explore commercial options.[39]

2.5.3.8 Public Access Wireless Infrastructures

The movement toward wireless technologies will gain even more momentum with the emergence of mobile Wi-Fi, mesh Wi-Fi (mesh-network), WiMAX, and Dedicated Short-Range Communications (DSRC), which are all expected to mature over the next two to five years. Each is expected to bring wireless and wide band capabilities to the mobile environment where challenges such as how to maintain connections in a vehicle moving through wireless coverage zones are just now being overcome.

These wireless approaches are of particular interest because municipalities and transit agencies across the U.S. are studying whether or not to build public access wireless infrastructures and the specific type of infrastructure if one is built. Many government agencies already own some amount of fiber optic infrastructure, so wireless access points could provide last-mile and hot spot coverage to users. This type of infrastructure can provide economic benefits to the community and may additionally reduce communications costs for public safety functions such as police, fire, and transit.

2.5.4 Challenges and Lessons Learned

2.5.4.1 Interoperable Communications for Emergency Management

A number of recent disasters, both natural and man made, have illustrated the need for transit communications, and especially transit police communications, to be able to interoperate with those of public safety and other regional agencies. Such regional interoperability does not necessarily imply a need for consistency of equipment or technology, but it does mandate at minimum having the capability to link various dissimilar communications systems and management centers (back end operations) with one another.

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[39] www.dot.ca.gov/hq/research/operations/edapts/edapts.htm.

2.5.4.2 Sub-Optimization of Design Constraints

Design constraints limit vendor flexibility in meeting the core needs of the agency, and may end up costing far more than they are worth. Common design constraints with respect to communications include:

- Limitations on the number or placement of radio antenna sites, which may unnecessarily impact performance;
- Specification of a particular communications technology, which may unnecessarily impact cost, performance, and supportability; and
- Requirements for a new fleet management system to make use of an existing radio system, which may also unnecessarily impact cost, performance, and supportability.

Agencies report that there are significant advantages to be gained through resisting the urge to sub-optimize design constraints to satisfy special interests within the organization. One mechanism found to be especially useful is to require a business case for any design constraints proposed for inclusion in the system specification. In this way the constraint can be more easily dropped if it turns out that satisfying it would cost more than it is worth.

2.5.4.3 Public Access Wireless Infrastructures

Several transit agencies have begun planning for the installation of wireless Internet access onboard vehicles. At the same time, some municipalities across the U.S. have already begun (or have completed) deployment of their own public access wireless infrastructures, while others have secured commitments from commercial wireless service providers for inexpensive wireless access for municipal services. In this rapidly changing environment, transit agencies considering wireless Internet installations are urged to work with municipalities to make themselves aware of market trends in their respective service areas so that they might take advantage of cooperative funding opportunities and avoid undertaking duplicative deployments that will be rendered surplus or obsolete almost as soon as their implementations are complete.

One potentially advantageous implementation strategy, which is just now emerging, is for transit agencies to install their own wireless Internet infrastructure only in those locations where it appears that there may be an insufficient market to support commercial implementation (e.g., along the rural legs of some intercity and commuter corridors, while working with individual municipalities to leverage local funding and commercial interests for installation in populated areas).

In some cases, the choice to deploy — or not to deploy — public access wireless infrastructures is being made by state legislatures. Out of respect for commercial providers, several of the legislatures have banned the deployment of these technologies by public agencies if they compete with the private sector. For example, Illinois recently enacted this type of law. However, many other towns and cities are still beginning to build fiber and wireless infrastructures to support public services,[40] either as truly public infrastructures or via compromise agreements for low-cost services through their local commercial providers. Thus, it is also important for agencies to be aware of their legislative environment when planning their wireless strategy. In all cases, proactive outreach to individual municipalities appears to be an important key to success.

2.5.4.4 Shifting Technology Needs

Some transit agencies are considering whether the use of cell phones and access to information via cell phones and personal digital assistants (PDAs) will be so common in our society that some transit communications projects may not be needed, or the benefit-to-cost ratio will be poor. For example, some transit ITS projects to install communications and electronic information at bus stops take many years to plan, budget, and implement. In addition to the implementation budget costs, ongoing operations and maintenance costs are added to the agency's operating budget. It is possible that if the project takes too long to implement it may not be needed, especially if personal access to data is widespread at the time of implementation.

2.5.4.5 User Support

Providing public wireless Internet access on a transit vehicle may place unexpected demands on the vehicle operator. Passengers need to be taught that bus operators and train crews are not equipped to answer questions or provide assistance with wireless access problems.

2.5.4.6 Evolving Technologies

2.5.4.6.1 "Just in Time" Technology Procurement

Information technology evolves at a far faster rate than do vehicles or facilities. Sometimes, information technology specified at the front end of a project will be two generations behind the times and no longer supported by the vendor community by the time the project is built. Performance requirements, test plans, and acceptance criteria can and should be specified up front, but procurement of the actual technology for delivering on those requirements should be delayed until just prior to actual installation. Moreover, it should be recognized that while emerging standards can offer real value, they are just that, "emerging" and subject to change. The issue of early migration to "emerging" communication standards and practices, such as in IP telephony, mesh networks, standard interface profiles, and other areas of convergence, should be examined carefully with a clear focus on risk management.

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[40] DeGraff, Kenneth, "Community Wireless Network: Why Not?" *Mobile Government: Point/Counterpoint, A Supplement to Government Technology*, June 2005, pp. 7-9.

2.5.4.6.2 Communications Infrastructure Supportability and Administration

To insure a cost-effective, reliable, and secure communications infrastructure, it is important that ITS communications be planned for integration of network management with the rest of the agency's IT communications infrastructure. Other supportability issues may include the need for new troubleshooting and maintenance skills, and possibly shorter equipment life cycles because some of the components in data radio systems are more like traditional IT equipment than the long-lived, more rugged radio equipment of the past.

2.6 Transit ITS Standards

A standard or protocol is defined as a set of rules or measures with which to compare or build similar objects. In 1995, the U.S. DOT initiated a standards program to accelerate the transportation industry's development, adoption, and deployment of technology standards for ITS. The transit industry started addressing these concerns back in March 1992[41] with the initiation of the ITS-America Advanced Public Transportation System (APTS) Bus/Vehicle Area Network (VAN) Working Group. Since that time, many other initiatives have been started by Standard Development Organizations (SDOs) to develop standards and best practices guidance for transit ITS systems in the U.S.[42]

The USDOT initiated the standards effort as a way of decreasing the time it takes to deploy technology and reducing ITS life cycle costs. In general, the adoption of standards has lowered costs and reduced the complexity of installing and operating electronic- and computer-driven systems. The FTA Policy on ITS National Architecture and Standards emphasizes that projects consider using industry standards for transit ITS deployments to benefit from lowered costs over the system life and to facilitate integration and interoperability. The ITS standards are conceptually mapped to the National ITS Architecture to support a traceable, end-to-end requirements process from planning to operations and maintenance.

2.6.1 Standard Descriptions

Standards may be classified in many different ways. The primary set of standard types needed by ITS applications fall into three major categories:

Interface and information standards;

[41] Watje, John, and Bill Kronenberger, "Data Communications Network for Transit Vehicles: SAE J1708 Serial Data Communications between Microcomputer Systems in Heavy Duty Vehicle Applications." In *Transit ITS Compendium*, Wilson, Lawrence, ed. Institute of Transportation Engineers, Washington, DC, 1997, pp. 34-38.

[42] Other standards activities have been ongoing at APTA such as PRESS as well as around the world to address ITS and other standards.

Communications technologies and standards; and
Device technologies and standards.

This section only deals with "interface standards." Details on communications protocols are discussed in Section 2.5, Communications. Device standards are briefly discussed in the relevant sections of the document or are outside the scope of this report. On the other hand, interface and information standards enable multiple systems to interact and share needed data. Generally, interface and information standards describe the semantics, formats, encoding, and behavior of information that is exchanged among multiple systems. There are typically many different information standards that must work together to ensure end-to-end interoperability. The information technology industry describes many standards to meet most application exchange and service functionality. These standard classifications are listed below in Table 5:

Table 5 Standard Types and Descriptions

Standard Type	Description
Business Semantics	Standards that describe user-driven requirements for target domain services and information
Orchestration / Dialog	Standards that provide templates and enforce requirements for exchanging messages and managing services
Security	Standards related to securing services and information
Discovery	Standards that enable a system to discover and understand features of a service, dialog, or message
Description / Metadata	Standards that describe the requirements deployed in a service, dialog, or message
Message Processing	Standards that describe the requirements for describing a message
Data Extraction	Standards for extracting information from a service or message
Data Semantics	Standards that enable a user to describe the meaning of information
Data Syntax	Standards that describe the format of information/data
Transformation and Encoding	Standards that describe how to efficiently change, encode, or decode the format of data
Transport	Standards that describe how to transmit information from one system to another

Many of these information standards rely on other standards to work effectively. For example, many mature and emerging standards are based on the World Wide Web Consortium (W3C) Extensible Markup Language (XML) and XML Schema standards. A standard that supports the description of another standard is called a "base standard." For example, the base standard used to describe the Transit Communications Interface Profiles (TCIP) messages is a business semantics standard called the World Wide Web Consortium XML Schema. A standard or group of standards that describe rules for how to apply a base standard(s) in order to ensure a high degree of interoperability is called a "profile." The framework for deploying information technology today depends on this IT standard classification and group of standards which together ensure compatibility among commercial off the shelf applications and tools.

Transit standards more closely tied to device and critical systems may use other sets of standards, for example, onboard vehicle systems for bus uses the SAE J1708 family, and rail uses the IEEE Rail Transit Vehicle Interface Standards (RTVIS).[43]

Among the standard development areas to be discussed in this section are:

- Integrated Fare Management Standards
  - APTA Universal Transit Farecard Standards
  - APTA Transit Communications Interface Profiles Fare Collection Business Area
  - ISO/CEN Integrated Fare Management Standard
  - INCITS Transit Fare Cards — Interoperability Framework for Contactless Fare Payment Technologies and Systems
- APTA Transit Communications Interface Profile (TCIP) Standard
- SAE Vehicle Area Network (J1708 Family of Standards)
- ISO
  - European Union Transmodel
  - Bus Numbering System
  - PRESTO
- ITS Related Standards
  - NTCIP 1211
  - NTCIP 2306
  - SAE ATIS/LRMS
- GeoSpatial One Stop

[43] IEEE rail standards are discussed in the context of rail systems in Chapter 8 – Intelligent Vehicle Systems.

2.6.1.1 Integrated Fare Management Standards

A characteristic of standards for fare collection is that there are many options and few comprehensive solutions at the time of this report. Existing and emerging fare collection standards address requirements for different levels within the overall fare management system architecture, from the front-end device level for performing card issuance, reading, and writing functions to the clearinghouse level functions. These functions and fare architecture levels are described in more detail in Chapter 4, Electronic Fare Payment. The functionality and interfaces between these architecture layers are associated with different, sometimes divergent standards.

2.6.1.1.1 U.S. Fare Card Standard Efforts

There are two U.S. efforts to generate standards for the electronic fare management system. The APTA Universal Farecard Standards effort (UTFS), initiated its work in 2001, and the APTA Transit Communication Interface Profiles (TCIP) began the fare collection section in 2004. In addition, there are international standards governing form, fit, and factor standards for media (e.g., card) standards.

2.6.1.1.1a Media Standards

The most popular card standards that are specified in the U.S. and Europe are ISO 7816 and ISO 14443 Type A and B. ISO 7816 is a contact card standard. The contactless integrated circuit card, ISO 14443, supports version Types A and B. The main differences between the two types consist of modulation methods, coding schemes, and protocol initialization methods. At this level, neither of these ISO standards addresses application issues for fare payment, such as card/media data layout, application commands, security, and other related aspects.

2.6.1.1.1b APTA Universal Transit Farecard Standards

The Universal Transit Farecard Standards (UTFS) effort is composed of three committees (Fare Media Committee, Operations Committee and Financial Management Committee) that address the various institutional and technical interoperability issues that arise with deploying integrated fare management systems.[44]

The Fare Media Committee was established to provide standards, guidelines, and best practices on magnetic fare media to the public transportation community. The committee deliverables are:

Trends in Electronic Fare Media — Completed and published

Farecard Procurement Guidelines and Specification for Magnetic Striped Instrument Design — Completed and awaiting ballot to be published

The Operations Committee was established to identify the critical elements essential to the implementation of an Automatic Fare Collection (AFC) System. In addition, the

[44] The following UTFS Committee descriptions are excerpted from Tam, Chung Chung, "Chung-Chung Tam — Cartes 2005 Revised 09-10-2005."

committee developed guidelines and recommended practices for transit agencies to use in planning, designing, procuring, implementing, and maintaining a local and/or regional AFC System. The committee deliverable is:

> AFC Planning and Implementation Guidelines — Completed and awaiting ballot to be published

The Special Industry Liaisons were identified to coordinate UTFS efforts with the I-95 Corridor Coalition to identify any interoperability issues and also with the Smart Card Alliance to obtain input from the financial industry.

The Financial Management Committee develops standards and guidelines related to all aspects of financial reporting, clearing, and settlement. Under the UTFS Financial Management Committee, two working groups, the Business Process Work Group and the Systems Work Group, were established to address the business and technical issues.

The two working groups have been prolific in planning and developing specifications, guidelines, and preliminary standard documents to address key interfaces between fare collection subsystems. These interfaces were assigned to four work packages (of which three are active):

> Work Package 1 (WP1): Card: Developing guidelines and standards related to smartcards.
>
> Work Package 2 (WP2): Card Reader: This work package has been eliminated.
>
> Work Package 3: Security: Addressing only the critical areas of concern for the security planning associated with the smart card-based components of AFC systems. (This work has been completed and published.)
>
> Work Package 4 (WP4): Back Office: Producing standards and guidelines to enable the interoperability between a single transit system's fare payment devices and a central computer system and interoperability between two (2) regional central computer systems.

Initially, the objective of the effort of UTFS Work Package 4 was to achieve interoperability at the component level, enabling vendor components to work within the same architecture level. This ambitious goal was revised to at this time to achieve subsystem interoperability, "in which a subsystem is defined as a 'black box' encompassing the Automatic Fare Collection (AFC) equipment, local computer, and central server."[45] Specifically, the subsystem that is most affected is the back-end where now only a messaging standard between the agency central computer system[46] and the local depot system[47] will be developed. This effort will be referred to as WP4+ as

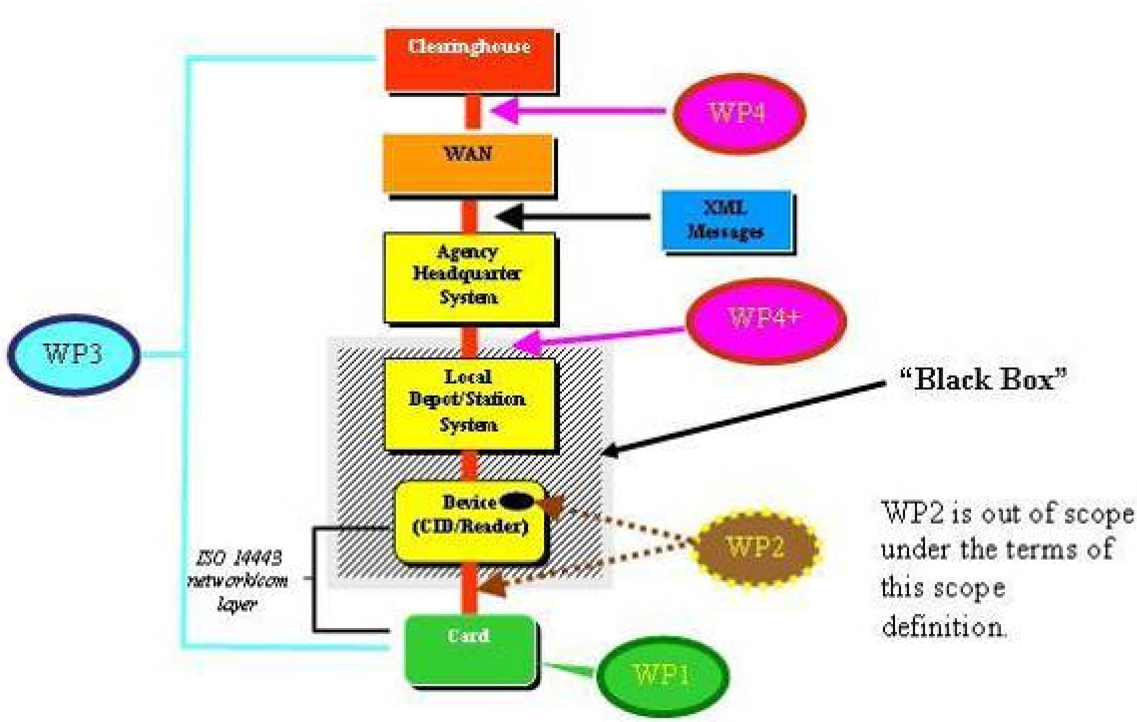
[45] Ibid. [Tam, 2005]

[46] Refers to Level 3 in the Electronic Fare System Architecture Figure 4-xx.

[47] Refers to Level 2 in the Electronic Fare System Architecture Figure 4-xx.

depicted in Figure 12. The standard that links the agency central computer[48] with the regional clearinghouse[49] referred to as WP4 is generally unaffected by the addition of WP4+.

Figure 12 UTFS Work Package (WP) Scope



2.6.1.1.2 Transit Communications Interface Profiles: WG 7 Fare Collection

Although its scope is broader than fare collection, TCIP only addresses the data descriptions and message exchange requirements for a single agency's bus fare collection system configuration and maintenance processes.[50]

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[48] Refers to Level 3 in the Electronic Fare System Architecture Figure 4-xx.
[49] Refers to Level 4 in the Electronic Fare System Architecture Figure 4-xx.
[50] Differences between UTFS vs. TCIP. UTFS is an end-to-end integrated fare management process for electronic media (magnetic and integrated circuit cards) that supports regional payment management systems. On the other hand, TCIP serves a single operator only for fare boxes on board buses. A comparison of the two is described in the table below.

Comparison of UTFS and TCIP Scopes (From "APTA RMC Agenda 20050321 - UTFS TCIP Coordination")

	UTFS	TCIP
Regional/Single	Regional System	Single Agency
Mode	Multimodal	Bus Only
Fare Media	Smartcards (Magnetic cards under consideration)	All Fare Media
Security	Security Guidelines	Not in scope
Clearinghouse and Regional Service Center (CH/RSC)	Clearing House and Regional Service Center Function	No CH/RSC Function
System Configuration	Not included	Only for fare box onboard bus
System Maintenance	Not included	Only for fare box onboard bus

The fare collection exchange requirements include interfaces for:

1. Command Disable Fare Equipment
2. Command Enable Fare Equipment
3. Load Fare Collection Data
4. Unload Fare Collection Data
5. Report Cashbox Event
6. Report Farebox Validation Error
7. Push Fare Data
8. Push Fare Zones
9. Report Cashbox Reconciliation
10. Report Vault Event
11. Subscribe Fare Collection Health
12. Subscribe Fare Passenger Data
13. Subscribe Daily Revenue Data
14. Subscribe Fare Equipment Subset Definitions
15. Subscribe Fare Zones

These farebox data sets may be uploaded and downloaded via short-range wireless or radio link as appropriate. (See Section 2.4.3.1 for more information on TCIP.)

2.6.1.1.3 International Efforts

There are numerous international standard development activities and standards that are emerging or deployed throughout the world. The European community supports several standards, and Japan and Korea also have nationwide standards. Many of these efforts cover card and device level interactions. Some may cover the local depot to central computer system levels as well. Few cover the central computer system level to the regional clearinghouse levels.

Until recently, there was little coordination among public transit operations throughout the world. However, recently the European Union's standards organization, CEN, brought the Integrated Fare Management System (IFMS) standard to the international community through the International Standards Organization (ISO) Technical Committee on ITS, Working Group 8 on Public Transport and Emergency. IFMS constructs a framework to describe the functionality, actors' roles and responsibilities, and alternative operational scenarios that define a comprehensive fare management system, encompassing the five levels described in the Electronic Fare Payment Architecture (as depicted in Figure 2-9), as well as extending those layers to merchant services.

2.6.1.1.4 INCITS Transit Fare Cards — Interoperability Framework for Contactless Fare Payment Technologies and Systems

The INCITS Transit Fare Card standard is being developed on a fast track as of the writing of this section. The standard is based on a specification and prototype spearheaded by the Port Authority of New York and New Jersey (PANYNJ) called the Regional Interoperability Standard (RIS). The RIS standard is also the basis for the UTFS Work Plan #1 and #4 programs.

2.6.1.2 Transit Communications Interface Profile (TCIP) Versions 2.x and 3.0

TCIP 2.x and 3.0 are APTA-led standards development efforts to develop a data interface standard that covers the following nine transit ITS business areas:

6. Common Public Transportation (CPT)
7. Control Center (CC)
8. Fare Collection (FC)
9. Incident Management (IM)
10. On board (OB)
11. Passenger Information (PI)
12. Scheduling and Runcutting (SCH)
13. Spatial Representation (SP)
14. Transit Signal Priority (TSP)

The standard is composed of messages and dialogs. Messages are used to exchange information between applications and dialogs describe the behavior of message exchange between the exchanging entities. For example, in the dialog "Subscribe Operator Sign On," a subsystem or process may send a request subscription message to the component that is responsible for the operator sign-on function. The responsible agent (or function) accepts and registers, or rejects the subscription. When operator sign-on information is available, the responsible agent then sends the logon information to all registered subscribers. The order of message exchange, messages, and their constituent data elements and groups of data elements (data frames) are described by the standard.

In developing these business semantics, TCIP must also describe the message transfer behavior between processes. These requirements are described in a series of Concept of Operations detailed in these eleven sections:

- General Concepts
- Security and Incident Mana gement Process
- PTV Operations Process
- Revenue and Fare Collection Process
- Scheduling Process
- Asset Management Process
- Personnel and Work Assignment Management Process
- Customer Information Process
- Data Repository Operations Process
- Spatial Data Management Process
- Transit Signal Priority (TSP) Process

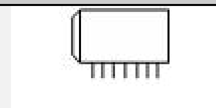
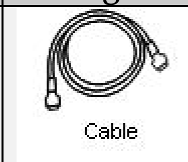
The standard uses Abstract Syntax Notation One (ASN.1) as its data description language, and the W3C — E**x**tensible **M**arkup **L**anguage (XML) and XML Schema standards as one of the preferred methods of data encoding conformance. The standard allows other encoding methods provided that they are defined by the systems exchanging information. No specific application protocol is recommended for transporting the message.

Conformance to the standard is based on the user (e.g., an operating agency) defining the Profile Requirements List (PRL), and the equipment or application developer describing the product operations in a Profile Implementation Conformance Specification (PICS) for each dialog that is implemented. Conformance is tested on an interface basis, not an application or system level. APTA plans to ballot the proposed standard in early 2006.

2.6.1.3 Bus Vehicle Area Network (SAE 1708 family of standards)

The Society of Automotive Engineers (SAE) family of standards for heavy-duty vehicles includes standards for application software, serial communications protocols, hardware and environmental conditions, and connector and cabling. Table 6 describes the basic application of each standard, with the appropriate standard listed at the bottom of the table. Older systems use the SAE J1708 standard, which supports low speeds (i.e., 1,200 to 9,600 baud) versus SAE J1939 which supports much higher baud rates (i.e., 4,800, 9,600 and 19,200 baud) used for safety-critical drivetrain (i.e., engine, brakes, etc.) data communications.

Table 6 Family of SAE Vehicle Network Standards

Physical Device			**Connector**	**Wiring**
Application Software	Communications Protocol Software	 Hardware		
Management of device/data, e.g., SW to get/receive, process, and transmit data through comm. interface; HW environmental rules	Valid data and commands; data definition; error recovery; rules for sending/ receiving	Voltage range Definition T/F	# pins Pin assignment Outlet	# wires; wire type
		Environmental specifications temp. vibration, dust, EMI/RFI, etc.		
Defined J1587 / J1939 J1455	Defined J1708 / J1939	Defined J1455	Defined J2496	Defined J2496

2.6.1.4 Related Standards Efforts

There are many standards currently under development that include transit systems. These standard efforts are divided into these three areas:

4. **ITS Standards:** Standards and emerging standards developed under the USDOT ITS Standards Program.
5. **International Standard Organization Technical Committee 204 Working Group 8 (ISO TC 204 WG 8):** Standard development activities contributed and under discussion by several participating countries.
6. **Geographic Information Framework Data Content Standard: Transportation / Transit (Part 7d):** An E-Government initiative to support the sharing of geospatial data sets and location services.

There are several standard development organizations in the U.S. that are developing standards that may be used by transit agencies to implement transit ITS. These standards are described below.

2.6.1.4.1 Signal Control and Prioritization (NTCIP 1211)

The NTCIP Signal Control and Prioritization (SCP) 1211 standard defines the functional entities of a Priority Request Generator (PRG) and a Priority Request Server (PRS), the two "actors" that request and grant priority treatment. The standard describes these actors in a logical sense. For that reason, the SCP standard describes four scenarios that correspond to the same scenarios referenced by the TCIP standard. The NTCIP and TCIP Standard Development Organizations' working groups coordinated the overlap in order to support the transfer of information between the "transit" subsystems to the "traffic" subsystems. The hope was that the similar approaches would ensure a high degree of interoperability. The NTCIP SCP committee will eventually add a fifth scenario to mirror the fifth TCIP scenario.

The NTCIP 1211 control and message formats are governed by NTCIP 8004 *Structure and Identification of Management Information*. NTCIP 8004 is based on the RFC 1157 *Simple Network Management Protocol* and RFC 1155 *Structure and Identification of Management Information for TCP/IP Based Internets.* NTCIP 8004 describes the managed objects found in the Management Information Base (MIB). Managed objects are defined in the Abstract Syntax Notion One (ASN.1) macro format and encoded in the NTCIP 1102 v.1.11 Octet Encoding Rules (OER).

The NTCIP standard is in the final stage of balloting and will be promulgated as a standard by the summer of 2006.

2.6.1.4.2 NTCIP 2306 Center to Center SOAP Interchange

The NTCIP 2306 standard provides a standards-based approach for discovering and exchanging query/response messages between applications. The standard, used for exchanging messages between ITS centers, is based on the W3C standard SOAP[51] and Web Services Descriptive Language (WSDL). SOAP and WSDL are supported by most off the shelf applications including Microsoft Excel. As such, the standard can be deployed in most application environments.

The NTCIP standard is in the final stage of balloting and will be promulgated as a standard by the summer of 2006.

2.6.1.4.3 SAE Advanced Traveler Information Systems / Location Referencing Message Specification

The two Society of Automotive Engineers standards contain the data dictionary and message sets needed to describe multimodal traveler information (ATIS) and location references (LRMS) information. Both these standards use the same base standards as those used by TCIP and other ITS information standards: ASN.1 as the data description language and XML as the means of encoding the messages. To this end, there is syntactic interoperability among the various ITS interface standards.

The ATIS standard describes messages related to traveler requests and responses on their multimodal travel plans including auto, bicycle, walking, transit, ferry, and more. ATIS incorporates TCIP data elements and data frames that are related to transit. Independently, the TCIP standard incorporates ATIS modal trip messages, data elements, and frames into the TCIP Passenger Information business area.

The TCIP standard also incorporates the LRMS data frames and elements as a way to describe location. These data frames and elements are used throughout the ITS messages, providing syntactic interoperability if not standard ways of specifying location information.

In addition, several US DOT ITS sponsored standards such as the IEEE 1512 Incident Management and ITE Standard for Functional Level Traffic Management Data Dictionary, in addition to TCIP, import both the ATIS and LRMS data frames and elements into their specified messages. Both these standards were balloted and approved in 2004.

Standard References:

Society of Automotive Engineers International (SAE). (2004-10). <u>Surface Vehicle Standard J2266 - Location Referencing Message Specification (LRMS)</u>

[51] The term SOAP is no longer used as an acronym to mean "simple object application protocol."

Society of Automotive Engineers International (SAE). (February 2004). Surface Vehicle Standard J2354 – Message Sets for Advanced Traveler Information Systems (ATIS)

2.6.1.4.4 Metadata and Archiving Standards / Standard Guide for Archiving and Retrieving ITS-Generated Data (E2259-03a)

Each system described in this report generates information that may be archived and later retrieved. For that purpose, metadata or data about the data may be stored and archived for analysis and administration purposes. The American Society of Testing and Materials (ASTM) developed a standard that presents "desired approaches to be considered and followed in planning, developing, and operating specific ADMS [Archive Data Management System] for the archiving and retrieval of ITS-generated data" [from www.astm.org]. The *E2259-03a Standard Guide for Archiving and Retrieving ITS-Generated Data* generally requires that three types of data be described as part of the event information:

Administration
Quality
Lineage (source and life cycle information)

There are currently no guidelines for transit systems on how to use the standard. Nevertheless, the approach described in the standard is considered "best practices" in the information technology industry.

2.6.1.5 ISO TC 204 Working Group 8

The ISO TC 204 WG 8 on Public Transport and Emergency is working on several standard efforts. The IFMS and TCIP (as a transit data interface standard) areas were discussed in Sections 2.4.1.1 and 2.4.2.1 above. Other areas under consideration include:

2.6.1.5.1 Transmodel

Several European countries have offered Transmodel, a European Union standard, as a conceptual data model to describe transit business areas.[52] The Transmodel data model uses entity-relationship diagrams (ERD) and documents an extensive set of data requirement descriptions. Transmodel differs from TCIP in that it uniquely and unambiguously defines the data concepts and their relationship in the transit information enterprise. The standard does not model data exchanges, and to that end, the Transmodel conceptual model has a very different purpose than TCIP.

The current version 6.0 is a mature model, based on the original version that was developed over a ten-year period from 1990 to 2000. Transmodel has spawned several interface standards that depend on the underlying data model and requirements to

[52] Transmodel site: www.transmodel.org or background information on http: www.transmodel.org.uk/.

describe the relationships among data elements and concepts. The most accessible standard to a U.S. audience is the United Kingdom's TransXchange, National Public Transport Access Nodes (NaPTAN), and National Public Transport Gazetteer (NPTG) standards. These XML-based interface formats support the exchange of service data, bus stop inventory, and public transport places for all registered transport companies. The data described by these standards are implemented in the UK TransportDirect Information Portal.

The proposal for using Transmodel is still in its early phases. A comparison between TCIP and Transmodel, as well as other national public transport data interface standards, is currently underway.

2.6.1.5.2 Standard Numbering System for Public Transport Stops (SNSPTS)

Although in its early stages of specification, the international community recognizes the need to develop naming conventions and approaches for the public to reference transit stops, be they bus stops, stations, or ferry berths. Several proposals are being considered for different regional levels, national, regional, and local. The specification will be submitted as a new work item in 2006.

2.6.1.5.3 PRESTO

The "Data Dictionary and Message Sets for Preemption and Prioritization of Signal System for Emergency and Public Transport Vehicles (PRESTO)" is a standard that addresses the message that is sent from a transit vehicle to a signalized intersection requesting priority treatment. This standard is based on the NTCIP 1400 TCIP series. The standard is a Committee Draft (WD) that will be submitted as a Draft International Standard (DIS) by fall 2006.

2.6.1.6 GeoSpatial One Stop (GOS): Geographic Information Framework, Data Content Standard, Transportation: Transit (Part 7d)

Driven by the E-Government standards initiative, the US Geologic Survey (USGS), and US DOT Bureau of Transportation Statistics (BTS) [now GITA], transit professionals from several agencies worked with experts in the geographic industry to develop a standard that details the requirements needed to exchange transit information that are tied to geography or transportation networks. The result of this effort was a combination of the Transmodel approach which describes a conceptual data model, and the TCIP approach which documents the information exchange needs between data source and application. Content described by the GOS standard, because it is so closely tied to the Open Geodata Consortium (OGC) location service specifications and Geographic Markup Language (GML) standard, may be used by applications that support those industry standards. The XML schema in GOS may use either LRMS or GML to represent geospatial data (like a point, segment, or path).

The standard was submitted to ANSI for balloting in early 2006, and should be approved later that year.

2.6.2 State of the Art

Many standards are under development or recently approved, although few have actually been deployed. The only widely implemented standards are the SAE 1708 family in buses and IEEE 1473 in trains. In addition, since NTCIP 2306 is based on existing W3C standards that are widely implemented across the IT industry spectrum, it may be viewed as a mature standard. Table 7 summarizes the maturity level associated with each standard set promulgated by the standard development organization or set of standards.

Table 7 Summaries of Standard Efforts

Standard	Description	Maturity and Deployments
Universal Transit Farecard Standards (UTFS)	Card content, Fare Collection Subsystem and Clearinghouse Standards and Guidelines	Emerging. Several standards are under development.
NTCIP 1400 series (TCIP 1)	Data Interface Standard	Implemented in Korean Trip Planning application using ASN.1 encoding. Several other agencies, such as SCAG and NJ Transit, are using TCIP as a data dictionary.
APTA TCIP 2.x/3.0	Message Exchange and Dialog Standard	Emerging. TCIP 2.4 was demonstrated in the TRB IDEA Project 39, Dynamic Timetable Generator – see Chapter 5.3.1.1 for more information.
SAE 1708	Bus Standards: multiplex communications, cabling and message sets	Adopted and implemented; J1939 is emerging for transit adoption, although it is implemented by other heavy-duty vehicle market segment.
IEEE RTVIS (Rail Transit Vehicle Interface Standards)	Standards for rail vehicles. Over 21 standards under development with 6 published and approved.	1473-1999: IEEE Standard for Communications Protocol Aboard Trains used onboard trains. First implemented RTVIS; deployed at several agencies, including NJ Transit.

Standard	Description	Maturity and Deployments
Transmodel	A conceptual data model developed by the European standards organization that describes transit ITS-related business areas, including personnel and performance data collection.	Mature: Used as the conceptual data model for several European exchange standards including UK TransXchange, NaPTAN, and NPTG.
NTCIP 1211	Signal Control and Prioritization	Approved in January 2006.
SAE ATIS	Advanced Traveler Information System	Approved, implemented in Gary-Chicago-Milwaukee (IDOT), San Francisco (MTC), Kansas City Scout Web site, Nebraska Dept of Roads, and Oregon DOT.
SAE LRMS	Location Referencing Method Standard	Approved, implemented in ATIS and Incident Management systems
NTCIP 2306	Center to Center message exchange standard	In balloting stage. Base standards, SOAP/WSDL are widely used throughout IT industry
E2259-03a	Standard Guide for Archiving and Retrieving ITS-Generated Data	Balloted. Contains limited guidance on transit operations data archiving.
GOS Framework	Geospatial Content Standard that includes transit layer along with several other transportation layers.	Emerging (demonstrated to share geospatial information between two border counties in California and Oregon)

Several demonstrations are implementing these standards; however, the projects are too new to uncover challenges and lessons learned at this stage.

2.6.3 Challenges and Lessons Learned

Few standards are actually implemented. Many projects are specifying the emerging standards and providing important lessons on implementation strategies such as checking for overspecification or deficiencies in the standards. From those that have demonstrated the standards, key lessons include:

- Always map requirements to the standards prior to specifying them in procurements. The standard may not capture all the information needed by an application or key elements may not be supported by the data sources supplying the information.

- Standards will not ensure that data are integrated across applications. Several data sets may be vulnerable to inconsistency. (See reference for "A Location Referencing Guidebook," Federal Transit Administration, April 2005, below.)
- Regional systems require regional data integration strategies. Many of these issues and data sets that are vulnerable to inconsistency are discussed in the Chapter 5.3, Transit Trip Information Infrastructure. Standards are not a substitute for sound data management policies and procedures.
- Systems need multiple standards working together to ensure interoperability. Understand how one standard interfaces with another to work together.
- Build on information technology (IT) standards such as W3C and OASIS to ensure interoperability, reduce costs (because the tools are readily available), and provide scalability and extensibility.

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Chapter 3 Fleet Management

3.1 Introduction

The term "Fleet Management" refers to the processes of planning, supervising, and optimizing the delivery of transit services, and also to the maintenance of vehicles providing those services. Automatic Vehicle Location (AVL) and Computer Aided Dispatch (CAD) systems are examples of technologies that facilitate the management of transit fleet operations, provide up-to-date information on vehicle locations to assist transit dispatchers, and inform travelers of route status.[53] Maintenance monitoring technologies allow for automatic collection and reporting of vehicle maintenance and condition information.[54] Moreover, a variety of Intelligent Transportation Systems (ITS) technologies including those that provide data from AVL/CAD systems and Automatic Passenger Counters (APC) can assist in the planning of new and existing transit services.[55]

ITS Fleet Management technologies are vast and include in-vehicle, field, and operations center systems. Integration of the various technologies and associated sensors allows individual technologies such as AVL, Wireless Communications, APCs, Transit Signal Priority (TSP), and others to provide benefits greater than any one technology could provide individually. Figures 13 and 14 illustrate many of the technologies and processes that are used and integrated into bus fleet management operations.

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[53] Intelligent Transportation Systems Technology Overview, US Department of Transportation, ITS Joint Program Office, Washington, DC, 2005. http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=TMandSubSystem=FMandTech=AVL.

[54] op. cit. http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=TMandSubSystem=FMandTech=Maintenance.

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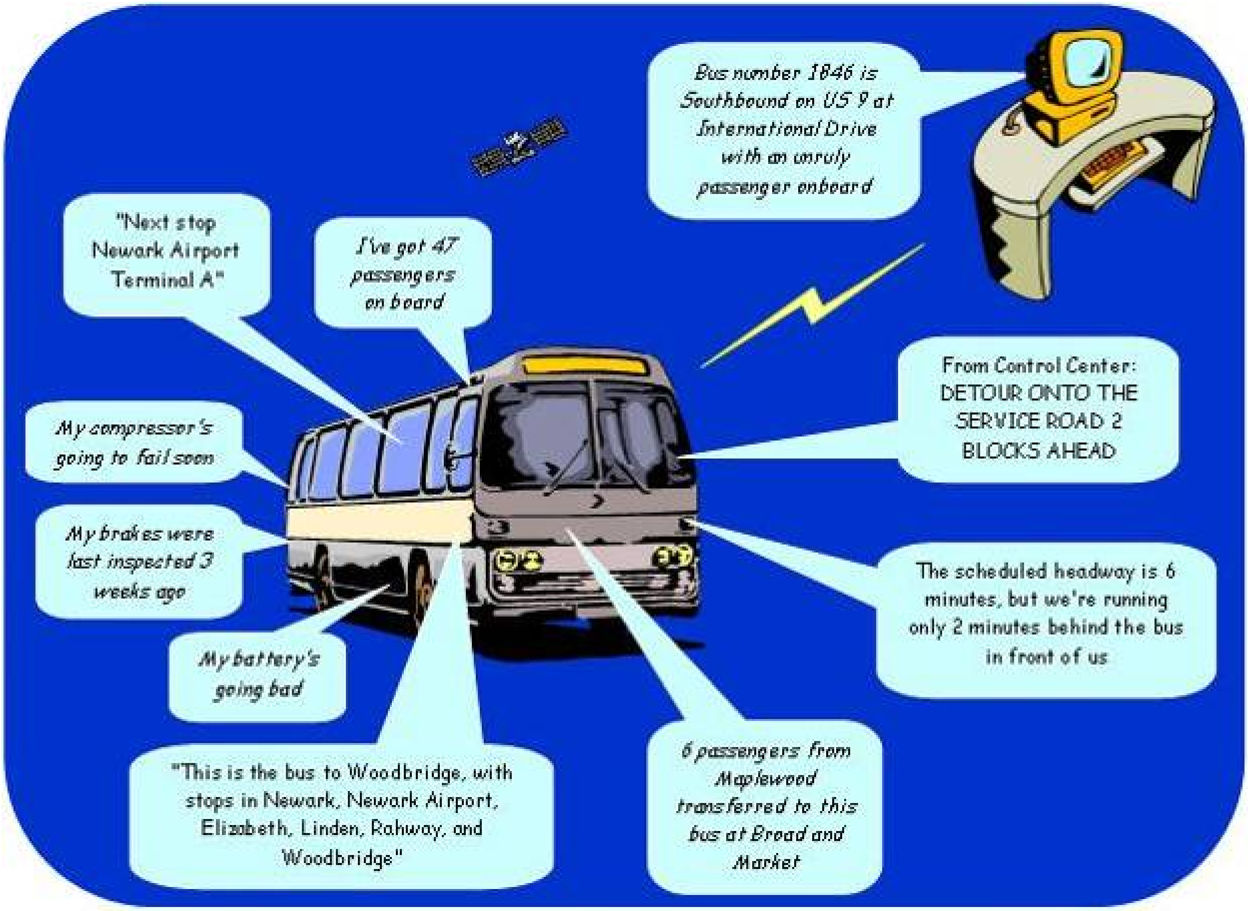

Figure 13 Fleet Management State-of-the-Art

ITS Fleet Management provides the means by which transit agencies can "bring it all together" for customers. In addition to obvious service supervision and maintenance management benefits made possible by the remote monitoring of vehicle position, on-time performance, and condition of various vehicle mechanical systems, Fleet Management technologies provide the basis for the various real-time incident management and passenger information applications discussed elsewhere in this report.

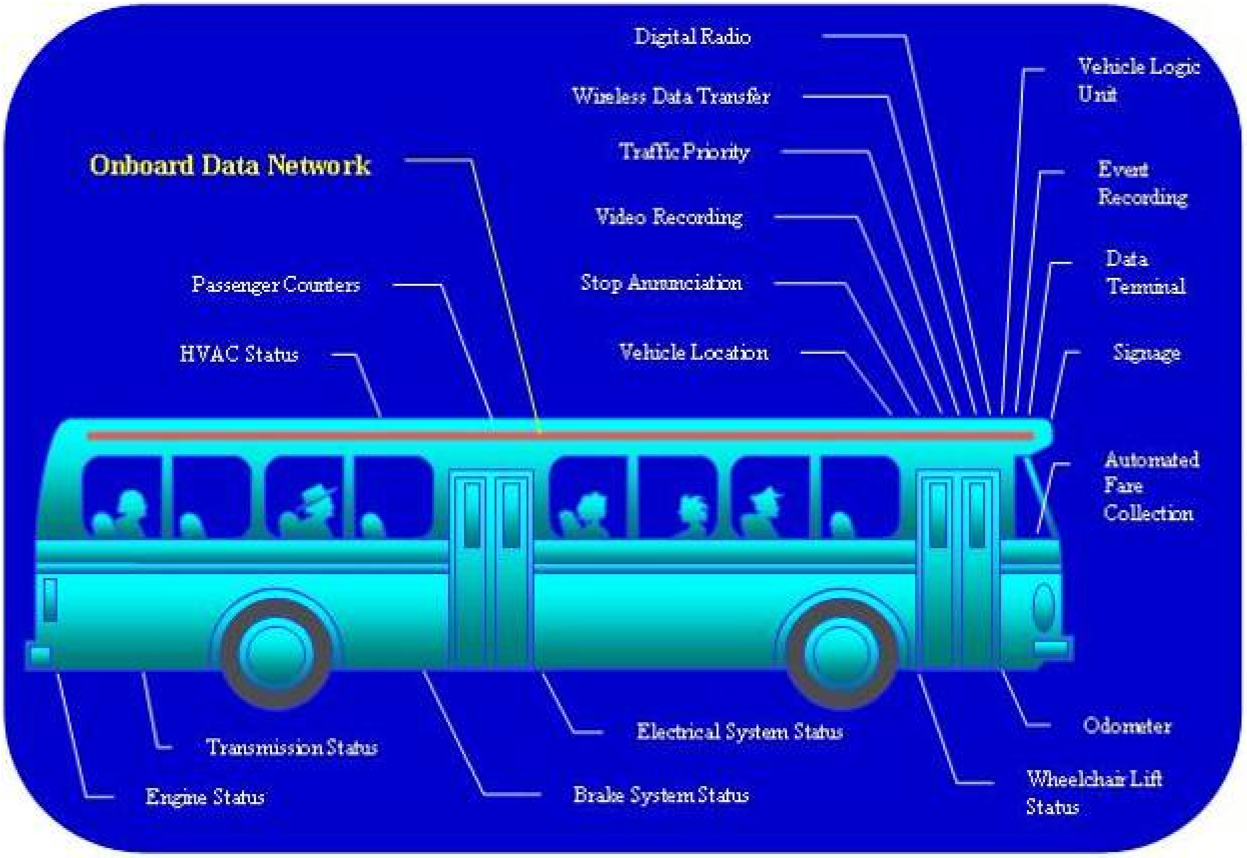

Figure 14 Fleet Management In-Vehicle Technologies

Fleet management can encompass many forms of vehicle and system control operations. For purposes of this report, ITS Fleet Management systems have been divided into four major categories:

- Service Planning Support Systems;
- Transit Priority Treatment;
- Maintenance Management Systems; and
- Transportation Operations Systems.

Transportation Operations Systems have been further divided into "Rail Operations Control Systems," "Bus Operations Systems," "Other Operations Systems" (i.e., passenger, facilities, HOV, multimodal), Dynamic Scheduling, and Paratransit Operations Systems.

3.2 Service Planning Support Systems

3.2.1 Technology Description

Service Planning Support systems include systems and business applications that support and process the information that flows to and from the fleet management systems. Since the Fleet Management System monitors actual service against expected service to optimize, control, and recover from incidents, the system is driven by service planning data concerning schedules, passenger facilities, network infrastructure, passenger loads, vehicle assignments, and vehicles. These data sets may require extensive processing on a monthly, weekly, or daily basis. This category of ITS applications includes developing the data sets related to the service plans (e.g., schedules) that can be processed by downstream systems used by customers, operators, and vehicles. (Additional details about these data sets are found in Chapter 2, Integration.)

Further, the various fleet management systems will produce gigabytes of transit performance and event data in a very short time. As a result, associated analysis tools must have the capacity to process and interpret these large volumes of data to support service performance and ridership reporting. The possibilities for deriving valuable information from these data are virtually unlimited and represent a critical element of a service planning support infrastructure.

Service Planning Support technologies include:

- APC — treadle mats, horizontal or vertical infrared beams, or machine vision applications that record the time, location and number of boarding and alighting passengers (and thus passenger load) at each stop;
- Automatic Vehicle Location (AVL) — specifically, schedulers need archived running time and headway reliability data from the AVL system;
- Route and pattern tracing tools (for onboard configuration data preparation);
- Performance data input to scheduling (as an interface only);
- Passenger facility planning tools (includes Bus Stop Inventory and field data collection applications);
- Reporting and visualization tools (decision support);
- Operator assignment management tools; and
- Electronic Scheduling Systems.

All of the Service Planning Support technologies mentioned above are commercially available.

3.2.2 State of the Art

State-of-the-art Service Planning Support systems are currently distinguished by such features as:

7. Passenger count accuracy in the two to three percent error range (which is about three times better than that commonly obtained with conventional manual counting procedures – commonly referred to as ride checks), even in vehicles with wide doorways, multiple passenger streams, and highly crowded loading conditions;
8. Automatic download and processing of running time and ridership data;
9. Automatic verification of reported route, run, and trip information based on actual path traveled;
10. Automatic passenger count balancing;
11. Automatic data cleansing to identify and filter data of questionable quality;
12. Automatic identification and reporting of failed passenger count sensors and equipment;
13. Seamless integration with third party data visualization, statistical analysis, and business intelligence tools;
14. Statistical ridership summaries by street, stop, route, trip, day, time of day, timepoint interval, and municipality;
15. Automatic calculation of running time distribution and variation by time of day for input into scheduling and run-cutting systems;
16. Automatic calculation of pre-trip recovery time required to ensure a given probability of on-time departure as a function of scheduled running time and observed running time variability;
17. Ability to respect stop occupancy and capacity constraints during scheduling; and
18. Integrated stop inventory maintenance.

State-of-the-art deployment examples:

19. King County Metro Transit, Seattle, WA

    While not the most advanced in terms of technology, King County Metro defines current state-of-the-art in terms of APC utilization, performance, and lessons learned in the U.S. Characteristics include:

    Considered by many to have one of the most highly developed APC data analysis and reporting programs, and most systematic use of APC data in the U.S.;

    Data are currently downloaded manually (will automate in future);

    Uses a mix of legacy treadle mat and newer infrared sensor technologies;

    219 of its buses are APC equipped (15 percent of fleet; roughly average for a partial fleet implementation);

    Uses automatic balancing and tuning of APC passenger counts;

APC counts are used for service planning, AVL running times are used for scheduling; and

There are currently no automated ties between APC and AVL systems (though both use same radio beacon "signposts" for position determination).

20. New Jersey Transit Corporation (NJ TRANSIT), Newark, NJ
    Though not yet widely deployed or used within the agency, NJ TRANSIT's APC technology is perhaps the most advanced in the U.S. The system makes use of:

    Overhead infrared sensor technology;

    Automatic data download;

    Automatic upload of updated vehicle software and data collection parameters;

    Automatic equipment diagnostics and failure reporting;

    Automatic data cleansing;

    Standards-based modular architecture;

    Multivendor interchangeable components;

    Seamless integration with third party database, reporting, and analysis tools; and

    Eight pilot buses (6 percent at one garage) and 17 low-floor articulated light rail cars (one complete light rail line) are APC equipped.

3.2.3 Emerging Trends

Most commercially available scheduling and run-cutting systems offer table-based facilities for maintenance of stop inventory and pattern stop list data within the vendor's proprietary database. Many users, however, have expressed a desire to be able to maintain these data using a map-based tool instead. Unfortunately, stop and pattern data contained in these proprietary databases are not readily accessible to the third party GIS (geographical information system) tools that agencies would like to be able to use. As an interim measure, work is currently underway by at least one vendor to automate an export/import process that would allow the tabular stop and pattern data to be maintained in a separate GIS database.

3.2.4 Challenges and Lessons Learned

Optimizing the data processing and reporting capabilities associated with an APC system to obtain ideal performance at a specific agency's operating environment may take years. Persistence is essential for meeting this challenge and achieving the desired results. As an example of the persistence required, operational data from AVL, APC, fare collection, TSP, and others must be cleansed and filtered before the data can be considered suitable for reporting. Additionally, route and trip attributions must be verified and anomalous data corrected or removed.

Agencies that have begun to share schedules and stop inventories electronically, either with other agencies or with other systems within their own agency, are finding that their efforts are being hindered by a lack of data consistency, continuity, and completeness. These agencies have found that the first step toward ITS implementation is to define an enterprise data model for stop, pattern, and schedule information, together with a consistent business process for stop and schedule data maintenance and updating.

3.3 Transit Priority Treatment

3.3.1 Technology Description

TSP systems use sensors to detect approaching transit vehicles and alter signal (i.e., traffic light) timings to improve transit performance and reliability.[56]

Transit priority treatment involves identifying approaching transit vehicles, determining whether priority is desired and the level and type of priority to be granted, and executing the appropriate signal priority strategy. Available strategies include extending the green light phase to allow transit vehicles to travel through, providing an early green light to allow transit vehicles to spend less time at an intersection, dedicated queue bypass lanes, and providing a special "buses only" signal where buses stop on the near side shoulder to allow buses right of way for rejoining the normal travel lanes. Other transit priority treatments include bus only travel lanes, and ordinances requiring that motorists yield to transit vehicles.

In theory, transit priority can be managed either at the intersection level (i.e., a "distributed" approach where buses autonomously request priority from upcoming intersections) or at the system level (i.e., a "centralized" approach where the transit management center requests priority from the traffic management center). In practice, according to the agencies surveyed for this report, transit priority has thus far most often been implemented using the distributed approach.

While transit priority has occasionally been implemented as an outright preemption of the normal traffic signal timing (most often in conjunction with commuter rail or light rail), or with a conditional priority set so high as to amount to outright preemption, this is not the norm. In most implementations, the logic for determining the level and type of priority to be granted can be quite complex, involving such variables as traffic

56 Intelligent Transportation Systems Technology Overview, US Department of Transportation, ITS Joint Program Office, Washington, DC. 2005. http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=AMandSubSystem=TCandTech=Priority.

volumes, queue lengths, intersection loading, vehicle type, direction, headway, persons on board, presence of a near-side stop, transit vehicle speed, frequency of priority requests, time since last priority, cycle length, schedule deviation, anticipated effect on overall signal coordination, and the point in the signal timing cycle when the request is first detected.

Transit Priority Treatment technologies include:

- Vehicle to wayside communications (radio, optical, tag readers, inductive loop, wireless fidelity [WI-FI], etc.);
- Signal Controller and Controller Cabinet;
- Center-to-Field communications; and
- Center-to-Center communications.

All of the Transit Priority Treatment technologies described above are commercially available and have been successfully deployed.

3.3.2 State of the Art

In addition to the various non-technical strategies available, most current implementations of ITS transit priority treatment provide conditional transit signal priority for transit vehicles approaching an intersection. The state of the art in TSP is characterized by a rule-based system that determines the need for a transit vehicle to be granted priority treatment. These rules consider the presence of a priority request by a transit vehicle, whether the bus/light rail vehicle is late or other criteria, and the capabilities of the signal controller in determining whether the request for priority can meet the operational policies of the traffic control agency (i.e., if the controller can extend or shorten a green light while not skipping any phases, braking coordination, etc.).

State-of-the-art TSP programs are distinguished by such features as:

- Senior staff members have extensive background in Traffic Engineering;
- Intersection controllers with the ability to support highly conditional priority algorithms based on traffic volumes, queue lengths, intersection loading, vehicle type, direction, headway, persons on board, frequency of priority requests, time since last priority, schedule deviation, and the point in cycle when bus is detected;
- Automatic logging of priority requests and actions taken;
- Automatic sensitivity analysis for identification of critical time point interval running times with greatest impact on vehicle requirements (i.e., in cases where signal priority, timing adjustments, queue bypass or bus only lanes might be most effective in reducing operating costs); and

Support for "what if" blocking and run-cutting simulations to identify likely impacts of transit signal priority and skip stop operation with respect to peak vehicle requirements.

State-of-the-art deployment examples:

- Pierce Transit, Tacoma, WA
  - Characterized by:
    - Few jurisdictions; and
    - Nearly unconditional priority.
- King County Metro Transit, Seattle, WA
  - Characterized by:
    - Many jurisdictions;
    - Highly conditional priority;
    - Highly intelligent transit signal priority processors housed in the signal controller cabinet;
    - Interface between the transit signal priority processor with the signal controller; and
    - Communication from bus to transit signal priority processor to signal the presence of a bus near the intersection.

3.3.3 Emerging Trends

Bus priority ordinances in New Jersey, Florida, Washington, and Oregon require motorists to yield the right-of-way to buses reentering traffic after picking up or discharging passengers. Coupled with aggressive enforcement (possibly aided by onboard digital video recordings), especially in areas where more time is lost trying to get back into the traffic stream than from waiting at traffic lights per se, such statutes might be expected to provide significant running time savings.

At least one signal controller manufacturer now offers controller modules with the intelligence required to actively manage signal priority in an effective manner without disrupting the overall traffic flow; other manufacturers are expected to follow. As traffic engineers become more familiar with this capability, resistance to signal priority implementation may decrease.

3.3.4 Challenges and Lessons Learned

The level of policy support for Transit Priority Treatment programs varies by jurisdiction. Ultimately, however, obtaining support from local traffic engineers may present a greater challenge than the policy support.

Making TSP or TPT acceptable to the region's traffic engineers involves funds that may not be available. For example, there are costs associated with modifying controllers to add the intelligence necessary to effectively manage priority calls and with modifying controllers and central systems to track and report call performance.

Agencies have found that even with a highly conditional priority strategy, average travel time savings on the order of five percent can be achieved. Perhaps more important, running time variation can be reduced, making schedules more reliable and allowing shorter recovery times between trips.

Transit agencies need to assist local traffic engineers through the learning curve; they are not necessarily familiar with the ability of modern systems to manage signal priority without completely disrupting traffic flow. Hosting seminars at local meetings of the Institute of Transportation Engineers (ITE) is an obvious first step.

Interagency agreements structured so that municipalities can feel they have the option to "walk away" if things do not work out may go a long way toward fostering acceptance of an initial signal priority deployment. Under this model, if a city chooses to cancel the project the agency simply takes back the equipment.

Agencies also need to help their schedulers through the learning curve; due to fear of issuing scheduled running times that turn out to be too short, there is typically great resistance to actually incorporating all of the available travel time savings into published schedules.

Seeking regional consensus for incorporation of signal priority into large signalization projects can add years to the implementation effort. It may be better to proceed with a small demonstration project first (i.e., one or two intersections) and then expand the effort if successful.

Knowledge of traffic engineering, intersection controllers, and tools is invaluable to the process. The knowledge allows the agency to understand traffic engineers' terminology and to address their issues and concerns.

When deploying signal priority, agencies should insist on sharing the maintenance. If not there already, agencies should maintain the network and the application software, and oversee maintenance management, failure detection, and reporting. In addition, regardless of who actually pays for the system, it is recommended that the city own (and maintain) the hardware located on the street as ownership of the field equipment will get the city vested in the system. It is also important to ensure that the transit signal priority processor can actually fit inside the existing intersection controller cabinet because not all will.

Establishing and maintaining communications infrastructures in the field can be difficult, both technically and institutionally. Therefore, it is recommended that a senior-level traffic engineer be hired to provide assistance. Transit agency personnel do not typically have the required traffic engineering vocabulary and credibility to facilitate the deployment of signal priority systems.

Many state departments of transportation are realizing the benefits made possible from upgrading their communications and intersection capabilities, updating signal controller cabinets, implementing closed loop control, and so on. A good time to discuss TSP and TPT with traffic departments is when they are planning to upgrade their intersections or traffic signal systems.

3.4 Maintenance Management Systems

3.4.1 Technology Description

Maintenance Management Systems perform many tasks, including the monitoring of major onboard vehicle components to provide warnings of failures and to help managers improve the effectiveness and efficiency of maintenance operations.

Maintenance Management Systems technologies include:

- Electronic inspection aids (providing voice and graphical instruction for vehicle and component inspection and troubleshooting);
- Fluids management systems;
- Inventory management systems;
- Interactive maintenance training systems;
- Remote vehicle diagnostics;
- Maintenance records management systems;
- Interactive electronic parts manuals;
- Warranty monitoring and management;
- Electronic component tagging (radio frequency identification — RFID)
- Vehicle health monitoring; and
- Electronic defect cards (allowing operators to report defects through an onboard data terminal).

All of the Maintenance Management System applications described above are commercially available.

3.4.2 State of the Art

State-of-the-art Maintenance Management Systems are distinguished by such features as:

- Automatic capture of propulsion, braking, and other onboard equipment status, alarm, and health measurement records that are tagged with current odometer, time, and location information;
- Automatic capture of component serial number and software version identification for all installed onboard electronic systems;
- Component serial number, software version, alarm and health information that is automatically transferred to the maintenance management system;
- Electronic tagging of refurbishable mechanical and electrical components such as wheels, actuators, alternators, radiators, and so on;
- Vehicle health and alarm information automatically analyzed to identify failed, failing, and misadjusted components;
- Operator-identified equipment defect information captured electronically onboard the vehicle;
- Operator-identified equipment defect information automatically transferred from vehicle to the maintenance management system in advance of vehicle arrival at the maintenance facility;
- Work orders and associated tools and parts lists required for corrective maintenance automatically generated in advance of vehicle arrival at the maintenance facility;
- Automatic identification of repeat failures of individual components;
- Automatic identification of warranty coverage of individual components;
- Full range of real-time equipment status and diagnostics information available remotely;
- Single-point-of-maintenance data access for all systems on a given vehicle; and
- Vehicle health and exception information for all installed systems (including propulsion, braking, fare collection, electrical, HVAC, wheelchair lift, AVL, etc.) centrally accessible via the onboard Mobile Data Terminal (MDT) and voice annunciator.

State-of-the-art deployment examples include:

16. Los Angeles County Metropolitan Transportation Authority, Los Angeles, CA

    Features include:

    - 2,400 buses equipped with onboard Maintenance Management Systems (100 percent of fleet);
    - Integration with maintenance and material management systems; and
    - Powertrain alarms transmitted in real time.

17. Pierce Transit, Tacoma, WA

Features include:

100 vehicles equipped with comprehensive maintenance data acquisition (40 percent of fleet).

18. New Jersey Transit Rail Operations, Newark, NJ

Features include:

Remote diagnostics and automatic real-time failure notification on 60 electric locomotives; and

Single-point–of-maintenance data access on more than 200 commuter railcars.

19. Chicago Transit Authority, Chicago, IL

Features include:

2000 buses equipped with onboard Maintenance Management Systems (100 percent of fleet);

Powertrain (engine, transmission, brakes, etc.) alarms transmitted in real time; and

Voice annunciation system used to report health status of ITS components.

3.4.3 Emerging Trends

Maintenance Management Systems are doing more than simply transmitting powertrain alarms. They are beginning to capture a variety of vehicle operating conditions such as temperatures, pressures, and voltages to support trend analysis for condition-based maintenance and prediction of impending failures.

3.4.4 Challenges and Lessons Learned

Tracking and identifying patterns of equipment failures is one of the biggest challenges facing Maintenance Management Systems. Being able to detect and repair a component failure is relatively easy. It is quite another matter to be able to recognize that specific units have been exhibiting a pattern of repeat failures — indicating that previous repairs have addressed only a symptom and that the root cause has yet to be uncovered. Agencies with state-of-the-art applications of Maintenance Management Systems have learned that tagging of field-replaceable units with electronic serial numbers that are scanned upon entry to the shop can greatly improve both their ability to detect repeat failures and their ability to track repair facility throughput and performance.

3.5 Transportation Operations Systems

3.5.1 Technology Description

Transportation Operations Systems are the so-called backend systems housed at the agency that support real-time operations of transit fleets. For this report, transportation operations systems have been grouped in the following categories:

- Rail Operations Control Systems
- Bus Operations Systems
- Other Operations Systems (Passenger, facilities, HOV, multimodal)
- Dynamic Scheduling and Paratransit Operations Systems

A typical state-of-the-art transportation operations system is illustrated in block diagram form in Figure 15 below:

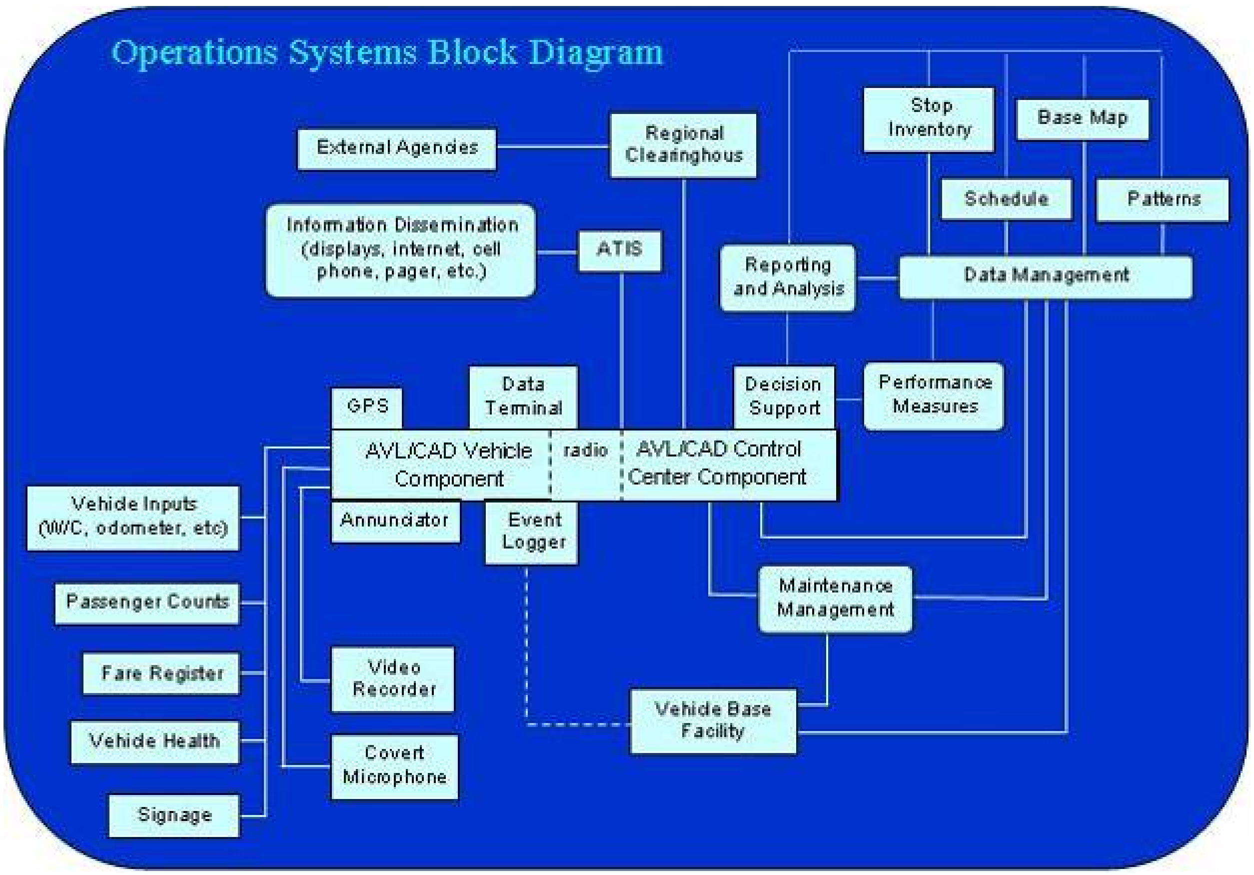

Figure 15 Transportation Operations System Block Diagram

3.5.1.1 Rail Operations Control Systems

Rail Operations Control Center Systems are comprised of computer software for rail control center functions that include train movement, power management, status monitoring, emergency response, estimated time of arrival (ETA) prediction, and decision support. Technology applications include:

Electronic vehicle identification;

Communications-based train control (CBTC);
Video processing;
SCADA (supervisory control and data acquisition);
Center-to-center communications;
Consist management;
Crew management; and
Interfaces to other fixed-end systems with need for real-time information.

The Rail Operations Control Center Systems described above are commercially available and widely deployed.

3.5.1.2 Bus Operations Systems

Bus Operations Control Center Systems are comprised of computer software that assists transit agencies in operating fixed-route bus service. They include ETA prediction functions such as vehicle location, route and schedule adherence, connection protection, communications management, and decision support. The Bus Operations System may be located at a fixed location or be portable. Technology applications include:

Computer Aided Dispatch (CAD), incident management and reporting, supervisor and maintenance dispatch modules, and remote CAD systems;
Vehicle and operator assignment and dispatch;
Yard/garage parking management; and
Interfaces to other fixed-end systems with need for real-time information.

The Bus Operations Control Center Systems described above are commercially available and widely deployed.

3.5.1.3 Paratransit Operations Systems

Paratransit Operations Systems include tools for the dispatch and operation of paratransit services that accommodate both standing orders and immediate requests. The system and its associated business processes may also support route deviation service and intermodal/interagency connections. Although eligibility, reservations, and billing systems of individual paratransit service providers are not specifically included in this category, information from scheduling and dispatch may be integrated back into the service providers' management information, billing, and accounting functions.

The Paratransit Operations Systems described above are commercially available and widely deployed.

3.5.1.4 Other Operations Systems

Other operations systems include Ferry Dispatch Systems, Passenger Operations Centers (i.e., those that monitor passenger facilities for elevator outages), and other centers where fleets of equipment are managed. These systems provide information on incident and facility outages to senior management, passengers at facilities, special announcements, and public relations (for media). Also included are HOV and multimodal operations (if run by transit).

The systems described above are all commercially available.

3.5.2 State of the Art

The state-of-the-art in Transportation Operations Systems provides supervisory and management personnel with a complete "picture" of the current status of the entire transit operation. Moreover, state-of-the-art systems present this total operations picture in an integrated way that makes it easy to understand and easy to formulate an appropriate response. In some cases, as with continual timing adjustments to prevent minor schedule and headway deviations from becoming big ones, response may even be fully automated. In other cases, systems may present a choice of recommended actions that an operator can choose to execute or not. It should be noted that the capabilities and performance available in state-of-the-art operations control solutions are truly extraordinary. In fact, relatively few agencies may have a real need (or budget) for all of the features available in this area.

State-of-the-art transportation operations systems are distinguished by a wide variety of advanced features such as those summarized below:

<u>Institutional features include</u>:

21. Statistically valid scheduled recovery times at the end of each scheduled trip (non technical enabling characteristic);
22. Gap vehicles (i.e., spare vehicles available to plug developing gaps in service) (non technical enabling characteristic);
23. Integrated dispatch, communications, passenger information, incident management, and security functions;
24. Sharing of information, video, and display assets with other transit and public safety agencies specifically for incident management and Amber Alert functions; and
25. Element of comprehensive integrated technology plan (non-technical enabling characteristic).

<u>Communications features include</u>:

26. Automatic monitoring of communications system performance, availability, communications coverage, and throughput and "request to talk" response time;
27. Continually updated virus protection;
28. Strict control of computing machinery and data networks, network firewalls, access controls, restricted administrative privileges, unused communication ports locked down, and so on;
29. Digital recording of all voice communications;
30. Logging of all data messages sent to and from the control center; and
31. Standards-based data exchange with communications protocol/technology decoupled from Control Center software, allowing single control center to coordinate operations of multiple divisions or service providers having different communications methods (e.g., cellular, satellite, 800 MHz, GSM) and in-vehicle technologies (e.g., from different vendors).

<u>Infrastructure features include</u>:

32. Redundancy of all critical functions and communications, with automatic failover;
33. Hardened, secure communications with diverse redundant paths;
34. Hardened control center environmental systems;
35. Accommodations and provisions for extended shift operations;
36. Physical access controls;
37. Uninterruptible power supplies with multiple backup power sources;
38. Physically separate backup control facility with redundant power, processors, and communications; and
39. Separate test environment with access to live data feeds.

<u>Operations Control and Supervision features include</u>:

40. Configurable automatic reporting of component failures, system performance exceptions, service exceptions, and user exceptions and overrides;
41. Headway monitoring;
42. Automatic tracking of hours in service for vehicle and control center operators;
43. Automatic exception notifications for route, schedule, and headway deviations, operators nearing hours in service limits, vehicles that will not arrive in time to make scheduled turn, vehicles lacking sufficient fuel for next scheduled trips, vehicles with mechanical problems, and others;
44. Operations decision support with automatic response within defined limits for headway and schedule adherence;
45. Terminal decision support with automatic response within defined limits for service continuity;

46. Transfer connection protection;
47. Route adherence monitoring;
48. Integration with maintenance management;
49. Playback capability;
50. Interactive training functions; and
51. Configurable user interface.

Incident Management and Reporting features include:

52. Onboard video surveillance and recording with ability to display real-time video at control center and in police and supervisory vehicles operating near the transit vehicle;
53. Facility video surveillance and recording with ability to display real-time video at control center;
54. Video processing (machine vision) to identify exception conditions at facilities (e.g., overcrowded platforms, dropped bag, etc.), and target operator attention;
55. Silent alarm with covert audio and video transmission to control center;
56. Automatic detection of unauthorized vehicle movements; and
57. Ability to retrieve digital imagery and aerial photography, and identify emergency access routes (especially for rail) for any point on any line to support incident management and operator training.

Data Archive features include:

58. Automatic detection and logging of component failures, service exceptions, user exceptions, and overrides;
59. Automatic association of reported vehicle location and delays with specific GIS roadway links, stops, mileposts, and intersections;
60. Automatic logging of missed trips and extra trips operated in addition to schedule; and
61. Operational data store with an interface to archived enterprise data.

Passenger Information features include:

62. Automatic tracking of facility status with automatic identification of routes and trips affected by facility closures, fires, elevator failures, and so on; and
63. Travel/arrival time prediction that is accurate to within one minute or 20 percent of the time remaining until arrival.

State-of-the-art deployment examples of Transportation Operations Systems include:

Los Angeles County Metropolitan Transportation Authority, Los Angeles, CA
Features include:

2,400 buses dispatched;
Video recording and transmission; and
Archived running time data fed to the Scheduling Department.

New Jersey Transit Rail Operations, Newark, NJ
Features include:
Nine rail lines dispatched;
477 route miles, 91 controlled interlockings, and 1,222 signals;
Real-time data exchange with Amtrak for train tracking on the Northeast Corridor;
Power dispatching;
Reduced dispatcher workload through support for stacked routes (series of intended routings for next few trains, pre-programmed by the dispatcher and executed automatically in sequence by the train control system as successive trains pass by);
Remote surveillance and control of movable bridges;
Integrated passenger information output (train control system automatically generates status and arrival information for every train at every station);
Integrated event playback; and
Integrated training environment.

3.5.3 Emerging Trends

3.5.3.1 Modularization

The move from proprietary communications protocols toward open communications standards such as APCO-25 is bringing the transit industry closer to the goals of interagency interoperability, incremental system renewal, and incremental system expansion without feeling "locked in" to a specific vendor. Decoupling the communications protocol from the AVL/CAD application will make it possible to implement open standards for vehicle-control center data exchange, allowing agencies to easily upgrade or replace their AVL, MDT, and CAD technology on a vehicle-by-vehicle, fleet-by-fleet, garage-by-garage, or center-by-center basis as opposed to an "all or nothing" approach.

This decoupling of communications from AVL/CAD will also make it possible for agencies to implement different communications solutions optimized for individual modes, providers, and service areas while maintaining consistency in AVL/CAD operation.

All of this, however, comes at a cost. General purpose communications standards, when used in bandwidth-constrained transit-specific applications, are expected to offer less than 50 percent of the information throughput available from proprietary solutions that have been specifically optimized for the transit environment. One method for limiting bandwidth usage that is gaining popularity as vehicles become "smarter" is to not "poll" the vehicles, but rather have the vehicle monitor its own route and schedule adherence and then transmit exception reports only. Such implementations conserve bandwidth even further by having the vehicles transmit their status less frequently the further they are from a scheduled stop.

3.5.3.2 Remote Vehicle Disable

The nation's Homeland Security Department is beginning to call for transit agencies to have the ability to remotely disable stolen transit vehicles. In response, some vendors have begun to offer this capability. The capability is still very much in its infancy, however. Reliability has not yet been proven and the potential does exist for unintended activation of the disable feature at inopportune times (due to electromagnetic interference, component malfunction, or deliberate attack).

3.5.4 Challenges and Lessons Learned: General Transportation Operations Systems

Transportation Operations Systems were the earliest of the ITS fleet management technologies to be widely deployed, so it is perhaps not surprising that it is in this area that the bulk of the industry's lessons learned knowledge can be found.

The ever-present challenges of system cost, quantity of data produced, and acceptance by operators, though still of concern, have already been discussed at length in previous state-of-the-art reports and are not specifically addressed in this update. Many new items, however, are addressed below.

3.5.4.1 Specifications

Concerning specifications, most public transit procurement documents, including some cited as "best practices," continue to follow a common formula that combines background, technical specifications, project management, proposal requirements, and other items into an interlaced, multithreaded document that is often circumspect and difficult to follow. These specification documents often state that the agency desires to procure an "Advanced Public Transit Management System" or something similar, but rarely succinctly define exactly what they mean by the term. Nor do agencies define in certain terms what they need to be able to get out of the system or the performance and behavior required under definable conditions of specific local interest. Agencies typically provide a great deal of technical design detail, but often neglect the business requirements that define the true basis for acceptance of the delivered system. Lacking this basic element, specifications often leave open the possibility that the delivered system will "meet the specification" yet will not fully provide the business tools or results the agency originally intended.

In this regard, the state of the art in ITS fleet management system specification and procurement, as currently practiced, is lacking. To the extent that procurement specifications include technical design detail, vendors are restricted in their ability to offer more cost-effective solutions, and agencies put themselves at risk for the quality of the end result. To the extent that specifications neglect high-level business requirements and acceptance test scenarios, vendors are denied critical knowledge of the agency's real needs. Moreover, agencies open themselves to misinterpretation of requirements, which severely limits their ability to hold vendors contractually accountable for the functionality, performance, and usability of the delivered system. Some of the lessons learned from agencies include:

- Start with the point; define the result that you need (i.e., business requirements) up front;
- Write for the vendor audience. Tell them what they need to know and the order in which they need to know it. Limit needless background, and avoid technical or procedural detail that can just as easily be proposed by the vendor or negotiated after vendor selection;
- Keep the specification organized. Group items such as agency background, vendor qualifications and proposal requirements in separate appendices where they can be easily identified, rather than spreading them throughout the technical specification. Keep design constraints (if any are really necessary) separate from business requirements; and
- Know your priorities and make them clear. Distinguish between truly "required" and merely "desired" features, capabilities, and characteristics.

A good specification is one that can also serve as an acceptance test procedure. Agency leaders most likely care a great deal more that a system will allow their staff to perform certain critical business tasks with a given level of reliability and fault tolerance than they do about what kind of technology the system runs on. These business-level expectations form the true basis for final acceptance of the delivered system, and should be specified in detail.

Therefore, procurement specifications should be constructed to clearly and distinctly specify the acceptance criteria for the end product or service in business terms. The FTA Best Practices Procurement Manual (BPPM) refers to this advanced type of specification as a "performance specification" (as opposed to a "design specification").[57] A sample specification format designed specifically to facilitate this kind of advanced procurement vehicle is provided below.

[57] Best Practices Procurement Manual, Federal Transit Administration, Washington, DC, revised October 2005, www.fta.dot.gov/9386_ENG_HTML.htm.

Agencies will note that it is only in defining how the agency will actually test the delivered system for final acceptance that the true business (i.e., mission) requirements become completely and unambiguously known. Taking the effort to do this up front often requires additional time in specification development, but pays great dividends throughout the remainder of the project in terms of improved quality, improved vendor relations, improved quality of schedule and budget estimates, and reduction of costly rework.

Agencies will also note that one does not need to be an ITS technology expert to write a good fleet management performance specification. In fact, due to the natural tendency for technical people to "cut to the chase" by jumping straight to their vision of a design specification, the more technical knowledge the author has, the harder it often becomes to exercise the discipline required to focus first on those critical business requirements that form the true basis for acceptance testing and for determining the ultimate success or failure of the project.

One potentially useful resource for peer-reviewed samples of state-of-the-art business-level performance specifications that are testable and technology-independent are the "open source standards" pages of the Transit Standards Consortium website at www.tsconsortium.org, currently under development. Another useful source is the ITS performance specifications (termed "*p_specs*") sections of the USDOT National ITS Architecture Web site.[58]

A sample performance-based specification template that agencies might find useful is included in this report as Appendix D.

3.5.4.2 Testing

Final acceptance testing of delivered computer systems throughout the U.S. has been found to be generally inadequate. For an agency to know that the delivered system actually performs as expected, the system needs to be explicitly tested against each and every business requirement found in the final contract specification.

The key to developing a comprehensive system test is to identify the special cases and boundary conditions that may be important to the agency and specifically verify the delivered system's behavior in the field against each and every one prior to system acceptance. Test scenarios (taken from real-world failures) for which agencies would specify and verify desired system behavior might include:

Receiving a new schedule while current schedule still in effect;

[58] National ITS Architecture Web site, US Department of Transportation, Washington DC, http://itsarch.iteris.com/itsarch/.

Change from standard to daylight time while vehicles are still operating from previous day (if schedule runs that late);
Loss of network connectivity to a tower site;
Loss of network connectivity to a garage site;
Loss of power at a garage site;
Loss of wireless LAN at a garage site;
Loss of communications with a dispatch center;
Loss of communications with a vehicle;
Restoration of previously lost communications;
Extensive vehicle movement without logon;
Planned connections/transfers;
Dispatcher assigned to 2 or more non contiguous (geographically separated) routes or territories;
Calls in queue exceed display space on screen;
Vehicle short-turned or reassigned to new route or trip in mid block;
Driver logon with good communications;
Driver logon with communications failure;
Driver logoff with communications failure;
Emergency alarm;
Locally reflected GPS signal (generating incorrect position indication);
Temporary loss of GPS;
Prolonged loss of GPS;
Loss of vehicle odometer;
Replacement of onboard computer;
Failure of APC component;
Update of onboard software;
Repeated interruption of vehicle power during wireless data transfer;
Repeated interruption of vehicle power during onboard system initialization;
Repeated interruption of vehicle power during system shutdown;
Loss of radio communications at a tower site; and
Vehicle transition from one tower site to another.

3.5.4.3 Vehicle Installations

Successful agencies have learned to include requirements for a detailed vehicle survey, installation plan, installation walkthrough, and prototype installation for each distinct vehicle make and model to be equipped. Many also require site-specific training of installation personnel.

3.5.4.4 Test Bench

Some agencies often include at least one vehicle equipment test bench (possibly as many as one per garage, depending on the system maintenance strategy to be employed) in their list of deliverables. The test bench typically includes all harnesses, connectors, power supplies, equipment, and components found onboard a vehicle, together with whatever emulators might be required to fully test a complete vehicle equipment suite in a simulated onboard environment. Such test benches have been found useful for factory testing, and as a valuable tool for ongoing system maintenance, failure isolation, and troubleshooting. It should be delivered to the agency prior to prototype vehicle installation.

3.5.4.5 Custom Development

Agencies often insist that vendors customize their systems to provide capabilities beyond those included in the off-the-shelf product. Sometimes this results in an enhanced product for which the vendor believes there to be a larger market. In this case, the vendor adds the new feature to its product line and provides support for routine upgrades and bug fixes accordingly.

More often, however, unless adoption into the standard product line (i.e., "productization") is specifically required by the contract, this results in a custom application for which the agency is the only customer.

In this later case, agencies need to recognize that they have just created an application that the vendor cannot support in the way the agency might assume or expect. All costs for upgrades, debugging repairs, migration to new versions of third party operating systems and databases, and so forth must be passed on to this one agency. They cannot be spread over a larger customer base because that larger base simply does not exist.

Moreover, agencies that insist on directing a vendor to develop and install custom applications against the vendor's better judgement should be prepared to accept liability and indemnify vendors for failure or misuse in the field. A prime example in this area would be the ability to remotely disable a vehicle. An agency that requires this feature of a vendor that has deliberately chosen not to offer it as part of their stock product should be prepared to accept liability for that decision.

3.5.4.6 Achievable Scope

Agencies successful in delivering projects that are complete, on time, and within budget have learned to "settle" first for a vendor's proven off-the-shelf offering, and then only later (after delivery and acceptance of the baseline implementation) have the vendor implement enhancements to the system to provide additional desired features or performance by adding narrowly defined incremental advances to the off-the-shelf product. A project that overreaches or overpromises is one that is doomed to failure and frustration for all involved.

3.5.4.7 Test Environment

Agencies often forget that they will need a separate, on-site parallel test environment in which to verify future enhancements or upgrades to the delivered system (and its related third-party report tools, communications, database management systems, drivers, administrative tools, and operating systems) after initial acceptance. The test environment should be procured concurrently with the production system, and may be configured to additionally serve as a training platform for new operators and administrators.

3.5.4.8 Ownership of Data

At least one agency has recently found itself in a relationship with a system vendor who has asserted ownership of the passenger information output of the operations control system. In order to disseminate this information to passengers, the agency must pay license fees on a per-stop basis. Agencies should carefully review proposed agreements for this sort of language, and should specifically require that any and all data (other than the actual operating software itself) collected by, resident in, or output from the operations control system is theirs to use, modify, and disseminate as they see fit.

3.5.4.9 Operational Flexibility

The design and provisioning of the transit service itself can easily limit the ultimate utility of even the most advanced operations systems. Adequate recovery time, gap buses, rescue vehicles, field supervision, operator training, and maintenance support must still be available if operators are to make the most of the new capabilities these advanced systems can provide.

3.5.4.10 Project Planning and Project Management

3.5.4.10.1 Comprehensive Technology Plan

Agencies that have embarked on fleet management system projects without first, or concurrently, developing a comprehensive technology plan have found that the practice leads to a flawed implementation and a poor APTS initiative. Agencies should explicitly specify integrated technology planning as part of the project when applying for federal grants so as not to be restricted in their use of federal funding for this critical element of system engineering analysis.

3.5.4.10.2 Risk Management

Agencies should allow time in the project plan for resolution of third-party risks (e.g., delays in obtaining FCC licenses, zoning for towers, DOT approval of dash-mounted equipment, availability of third party data, etc.). Agencies should also require vendors to submit lists of uncertain items in their proposals. It is recommended that agencies develop contingency plans for risk response, then allow time and budget for contingency plan execution (e.g., for redesign, contract extension, etc.) in the event that these risks actually materialize.

3.5.4.10.3 Dedicated Project Manager

Just as vendors need to have a project manager (PM) who is always available to the customer, it is recommended that agencies have a project manager with project management (i.e., decision making) authority who is always available to the supplier. Experience indicates that agencies should assign a dedicated full-time project manager to any project expected to consume over $200K per month. Agencies should additionally assign a deputy PM to projects expected to spend over $1M per month to ensure on-time delivery and continuity of control.

3.5.4.10.4 ITS Architecture Policy Compliance

The FTA Policy on ITS architecture consistency is far less a technical requirement than a procedural one. Central to ITS architecture consistency is the requirement for an "ITS System Engineering Analysis." Consisting of a sound system engineering and project development practice, the FTA Policy is designed to ensure a high probability of project success, and is looked on by project management professionals more as a helpful checklist than as a burdensome federal regulation. This procedural requirement is intended to ensure (and requires documentation of) appropriate stakeholder consensus, value engineering, and requirements analysis, and is a direct project manager responsibility. Agencies that assume the system engineering analysis to be a mere technical detail and fail to adequately train their project management personnel to perform them risk noncompliance and loss of federal funding for their ITS programs.

3.5.4.11 Procurement

3.5.4.11.1 Value Engineering

Relatively unimportant "casual" specification items included in the procurement document often drive up cost. Agencies should take advantage of pre-proposal conferences to discuss cost drivers with prospective vendors, and reissue specifications accordingly. They may also want to revisit the issue again during proposal evaluation when they can issue revised specifications and request revised proposals from short-listed firms prior to vendor selection. Inclusion of 200-300 hours for detailed value engineering consultation following contract award has also been found to be helpful.

3.5.4.11.2 Canned Specifications

Rather than settle for a modified copy of a specification originally created for someone else, agencies should make the effort to identify actual needs for their own specific environment. Otherwise, agencies risk buying and incurring additional operating and support costs for items that they do not actually need, and also risk missing some of the more important items.

3.5.4.11.3 Quality of Proposals

Successful agencies have learned to fight the urge to hide the budget when advertising a request for proposals (RFP) or invitation for bids (IFB). Vendors' profit margins are self-regulating in a competitive procurement environment; knowledge of the project budget will only allow prospective suppliers to develop more reasonable proposals that more closely address the agency's actual intent.

3.5.4.11.4 Procuring for Best Achievable Value

Current competitive procurement provisions in Federal Acquisition Regulations (FARs) are sub-optimized to deliver either best quality or lowest purchase price, but not necessarily the best value (quality per dollar). Following are suggestions for obtaining best value on a federally funded project without violating the FARs.

The IFB process is not recommended for ITS procurements. However, it can be made to work if needed. In procuring for best value under either a one-step (i.e., low price) or two-step Brooks Act (i.e., best quality) IFB process, the key is to pre-qualify vendors through live demonstration prior to bid acceptance, to evaluate bids based on total net cost rather than just initial purchase price, and to be able to place a reasonably defensible monetary value on just how much a given "desired" system characteristic is worth to the agency.

Total cost is initial purchase price plus five to seven years' worth of maintenance and software support (which can be solicited as an option, whether the agency actually intends to contract it out or not), plus agency support and project management over the duration of the project (which can be calculated in terms of some representative number of dollars per month based on history).

The offsetting value of any "desired" items that a proposer commits to deliver is represented in the bid evaluation process as a credit that serves to reduce the total net cost to the agency. In this way, the agency can award to a vendor that offers the best total value, not just the lowest initial purchase price.

The RFP process is preferred for ITS procurements. In procuring for best achievable value under a RFP process, the key is to weight the evaluation heavily in favor of the off-the-shelf offering that satisfies the greatest number of your most important "required" specification items at the lowest total cost. Following deployment and acceptance of the selected off-the-shelf product, further enhancements can then be developed and deployed at a later time as long as the budget allows.

The RFP should ask for proposals in a minimum of two sections. The first is a base proposal for off-the-shelf "in-stock" functionality only, noting specifically any exceptions where specified “required” or “desired” functionality will not be met. The second section is an option for upgrading the off-the-shelf product to provide the full range of any remaining functionality and features described in the technical specifications. This second section should be delivered as a series of options that would allow the agency and the vendor to work together to value engineer the most cost-effective solution. It is also possible to specifically request an intermediate proposal identifying costs (if any) for upgrading the off-the-shelf offering only to the point where it could meet some minimum functionality level (the truly “must haves”) defined by the agency.

The off-the-shelf version will likely be a highly capable, tightly-integrated unit that gives the agency most of what it is looking for, but with proprietary interfaces that lock it into a single vendor for maintenance, upgrades, and expansions. The smaller the ultimate scope of deployment, the shorter the expected lifespan of the system, the more confidence the agency has in the vendor, and less likely the prospect of future enhancement or expansion, the less objectionable these tradeoffs become. If an agency finds that it can live with the off-the-shelf version, or with some minimum intermediate feature set, either as an end product in itself or as a starting place for subsequent customization following initial delivery and test, it may be able to save 30 -50 percent (or more) off the cost of the system by sticking with an off-the-shelf product rather than forcing a vendor to develop something new practically from scratch.

“Total cost” in the RFP process, as for the IFB, is initial purchase price, plus 5-7 years’ worth of maintenance and software support, plus the cost of agency support and project management over the duration of the project.

Both the National Transit Institute and the National Highway Institute offer valuable courses in ITS procurement.

3.5.4.12 Standards

3.5.4.12.1 Use of Standards

Best practices for use of standards have yet to be formalized. Thus, agencies are cautioned to avoid simply specifying “compliance” to a standard or “consistency” to an architecture.

It is too easy for a vendor to “comply” with a standard, yet not provide the multivendor interchangeability the agency thought it was getting. Given the current state of standards implementation, if agencies desire a specific modular architecture, then they need to define the specific interfaces they care about and spell out their behavior in detail.

Alternatively, agencies may allow the integrator to define it for them, but then must require that they receive the interface control documents as deliverables with full rights for royalty-free distribution and reuse.

At a minimum, agencies should require detailed interface specifications for all flows defined in the Regional ITS architecture, sufficient to allow qualified third-party suppliers to provide interoperating modules without the need for further vendor assistance.

One potentially useful resource for peer-reviewed samples of specifications for use of national standards in ITS procurement is the "open source standards" pages of the Transit Standards Consortium Web site, currently under development at www.tsconsortium.org.

3.5.4.12.2 Transit Communications Interface Profiles (TCIP)

While some question the recent federally sponsored TCIP Dialog development effort (TCIP 2.X), the original TCIP data dictionary (NTCIP 1400 - 1408) remains a valuable resource. Standard interfaces based on the TCIP data dictionary have been successfully implemented by the Southern California Association of Governments, New York State DOT, and others. The NTCIP 1400 series documents are well suited for facilitation of interface designs involving flat file transfer via XML (a common language for data representation), and provide a solid basis for standardization of intra-agency and interagency data exchange. As of this writing, they are electronically available free of charge in an easy to use Microsoft Access database format, from the Institute of Transportation Engineers at www.ITE.org.

3.5.4.12.3 J1708 Compliance

SAE J1708 and its commonly associated sister standards (or virtually any network standards currently in use) provide for locally defined codes and a "data link escape" message that makes it possible for a vendor to be "compliant" with the standard while nonetheless implementing a proprietary system architecture that denies the user the multivendor interoperability and interchangeability they thought they were specifying when they required use of the standard. The addition of the phrase "without use of the data link escape message or any vendor-defined MIDs or PIDs, except when using the J1708 network to accomplish software upload and file transfer operations not directly supported by SAE-J1587" to any specification requiring "J1708 compliance" should go a long way toward removing this ambiguity. Also, agencies have learned to explicitly specify SAE-J1587 as the message standard to be used with the J1708 transport protocol, and to include a complete description of the request-response behavior required of each distinct component on the network.

3.6 Lessons Learned: Rail Operations Control Systems

3.6.1 Dark Territory

While a train control system would appear to provide the ultimate controlled environment for vehicle location and passenger information, it does have its limitations. Train control systems have traditionally relied on track circuit occupancy to follow the location of trains across the network. While this works well for trains in a "controlled territory," there are many areas on a railroad — especially yards and terminals, and even portions of lines that may be controlled (i.e., dispatched) by other railroads — that may not be visible to the agency's train control system. For these areas that are "dark" to the agency's train control system, GPS can provide an invaluable supplement to conventional track circuit-based train location.

3.6.2 Train ID

Train control and signal systems are very good at keeping trains safe by preventing routings and movements that could lead one train to move onto a track that is already, or will soon be, occupied by another. *Which* train is immaterial, all that really matters to the train control system is that *some* train is occupying the track. The dispatchers need to know which trains are which, but the system does not. As soon as the train control system is used for fleet management, performance measurement, and passenger information, however, then electronic knowledge of vehicle identification and train assignment (i.e., exactly which vehicle is present at a given location and which scheduled trip it is currently operating) becomes critical.

A problem common to many train control systems is that this critical information may not be known (electronically) in a timely manner. Often, depending on dispatcher workload, trains may travel for some miles before they are positively identified to the system. Related passenger information generated by the system during these periods will be of questionable quality at best.

The most advanced train control systems ensure quality and consistency by automatically comparing train identification data entered onboard by the train crew with that proposed by the train control system (usually based on schedule) when the train passes a dynamic tag reader or GPS reporting point when first appearing in controlled territory. The dispatcher is thereby relieved of much of the burden of train ID verification, resolving only those cases where the system and the crew's input disagree, and train identification becomes automatically known to the system in a far more timely and reliable manner.

3.7 Lessons Learned: Bus Operations Systems

3.7.1 Designing for Modular System Upgrade and Expansion

The key to modular system upgrade and expansion is a tiered modular architecture with provisions for distributed parallel processing (for scalability) and well-defined standards for critical system interfaces (for modularity). At a minimum, the following interfaces should be fully standardized with no allowance for vendor-specific codes or formats:

Interfaces between in-vehicle subsystems (typically over a SAE J1708 network). Example: Interfaces between data terminal, vehicle locator, odometer, vehicle identification unit, fare register, fare card reader, destination signs, event recorder, powertrain, passenger count processors, and so on.

Interfaces between in-vehicle and vehicle base components (typically over an IEEE 802.11 wireless LAN). Example: Interfaces between fare register and garage computer, between event recorder and garage server, and between destination sign controller and garage server.

Interfaces between vehicle base components and central processing facility (typically over an IP network). Example: Interfaces between garage server and enterprise data warehouse.

Ultimately, the interfaces between CAD and radio, and between radio and AVL, may one day also be standardized, which will effectively decouple the in-vehicle and fixed base components of the CAD/AVL system. While there is no question that the idea of complete independence from any one system vendor has broad appeal in principle, it is still an open question as to whether this is truly necessary or even desirable in the real world. The question is currently an academic one in any event, as the present state of the art does not yet provide this final level of CAD/AVL modularity.

3.7.2 Communications

On average, commercial wireless providers (i.e., cellular) would appear to have adequate capacity to handle transit applications in a reliable and timely manner. However, incidents and emergencies can occur at the local level. The additional wireless traffic induced by these local incidents may quickly flood individual cell sites where the agency needs communications the most. To guarantee availability, most agencies currently still opt to operate their own private wireless network, even in locations where it might appear on the surface that commercial services may be more favorably priced. This situation may soon be changing, however, with the trend toward greater reliance on data rather than voice communications, which is far less bandwidth intensive.

3.8 Lessons Learned: Paratransit Operations Systems

3.8.1 Multiple Providers

Paratransit operations typically involve a number of small contracted service providers. The individual providers are usually too small to need, or afford, a modern fleet management system, yet together they may comprise a sizable fleet that the agency needs to be able to manage effectively. Taking advantage of the economies of scale available to a regional coordinating body, state-of-the-art paratransit operators have often opted to supply their providers with the necessary communications, dispatch, electronic maintenance, and administrative services free of charge.

3.8.2 Verification of Service Delivery

Paratransit operators have learned the hard way that fraud, typically in the form of inflated ridership figures or trips billed but never made, is too often an everyday part of life. State-of-the-art operators have developed independent cross-checks, often through integration of vehicle location with an electronic fare collection system, to verify reported ridership, billed trips, and service performance.

3.9 Lessons Learned: Other Operations Systems

3.9.1 Elevator and Escalator Status

Modern SCADA (Supervisory Control And Data Acquisition) systems can automatically collect all manner of operating and maintenance data from elevators, escalators, climate control, public address, ventilation, and electrical distribution systems. In addition to notifying operators of specific platforms affected by failed equipment, this information (especially escalator and elevator status) can be automatically made available to disabled customers considering travel to an affected station. The time for a customer to find out that the elevator is out of service is not just after the train has left that customer on the platform.

3.9.2 Crowd Control

Especially in times of service delays or disruptions, platforms can become unusually crowded, sometimes dangerously so. Agencies that have implemented widespread video surveillance of station platforms have found digital video technology invaluable for identifying and managing potential crowd control problems.

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Chapter 4 Electronic Fare Payment

4.1 Introduction and Technology Overview

Electronic fare payment provides an automated means of collecting and processing fares for public transportation services such as bus, rail, ferry, and other modes. Public transportation users can select from a variety of fare products, such as magnetic stripe cards (read-only or read-write), smart cards with varying levels of memory and computing power, or credit cards to pay for transportation services. The description of electronic fare payment in this report is organized into three major categories:

- Fare Systems
- Fare Products (Media)
- Clearinghouse/Regional Service Center (CH/RSC)

These categories have been structured to correspond with the significant work undertaken by the Universal Transit Farecard Standards (UTFS) Program being funded by the United States Department of Transportation (USDOT) and coordinated by the American Public Transportation Association (APTA). As discussed in Section 2.6, the UTFS program seeks to develop standards, specifications, and guidelines for electronic fare payment systems throughout North America.

Although this report discusses fare systems, fare products, and the Clearinghouse in different sections, all three elements need to work together in a transit electronic fare payment system. The section on the Clearinghouse/Regional Service Center highlights the importance of integration when deploying a regional fare system that involves multiple agencies. In regional fare systems, integration can occur at a number of levels to help facilitate seamless fare payment, including an integrated approach to fare policies, fare media or card reading standards, fare equipment, and revenue reconciliation.

In the last few years, steady progress has been made in the implementation of automated fare collection systems and the development of standards. In addition, the cost of sophisticated fare products, such as smart cards, has decreased, thereby making the systems more affordable to a wider range of public transit agencies. Like other ITS areas, there has been a push for integration of transportation services to support more seamless travel between modes, such as rail and bus, as well as different regional transportation providers.

4.2 Fare Systems

4.2.1 Technology Description

A fare system can be defined as the functions and equipment used by a transit agency to deploy a fare collection system. These systems may be closed systems, which are typically defined by an agency or region that accepts fare media from only one issuer and only support transportation services. In contrast, open systems accept fare products from multiple issuers (such as credit cards). An agency's electronic fare payment system may include components such as:

- Ticket vending machines (TVMs);
- Point of Sale (POS) terminals;
- eCommerce Web sites that sell fare products;
- Manned card issuance and revaluation networks;
- Fare gates and turnstiles;
- Card readers and validators;
- Depot and station computers;
- Customer service centers;
- Merchant sales outlets;
- Central computer systems; and
- Clearing and settlement functions to support revenue reconciliation and other fare data analyses.

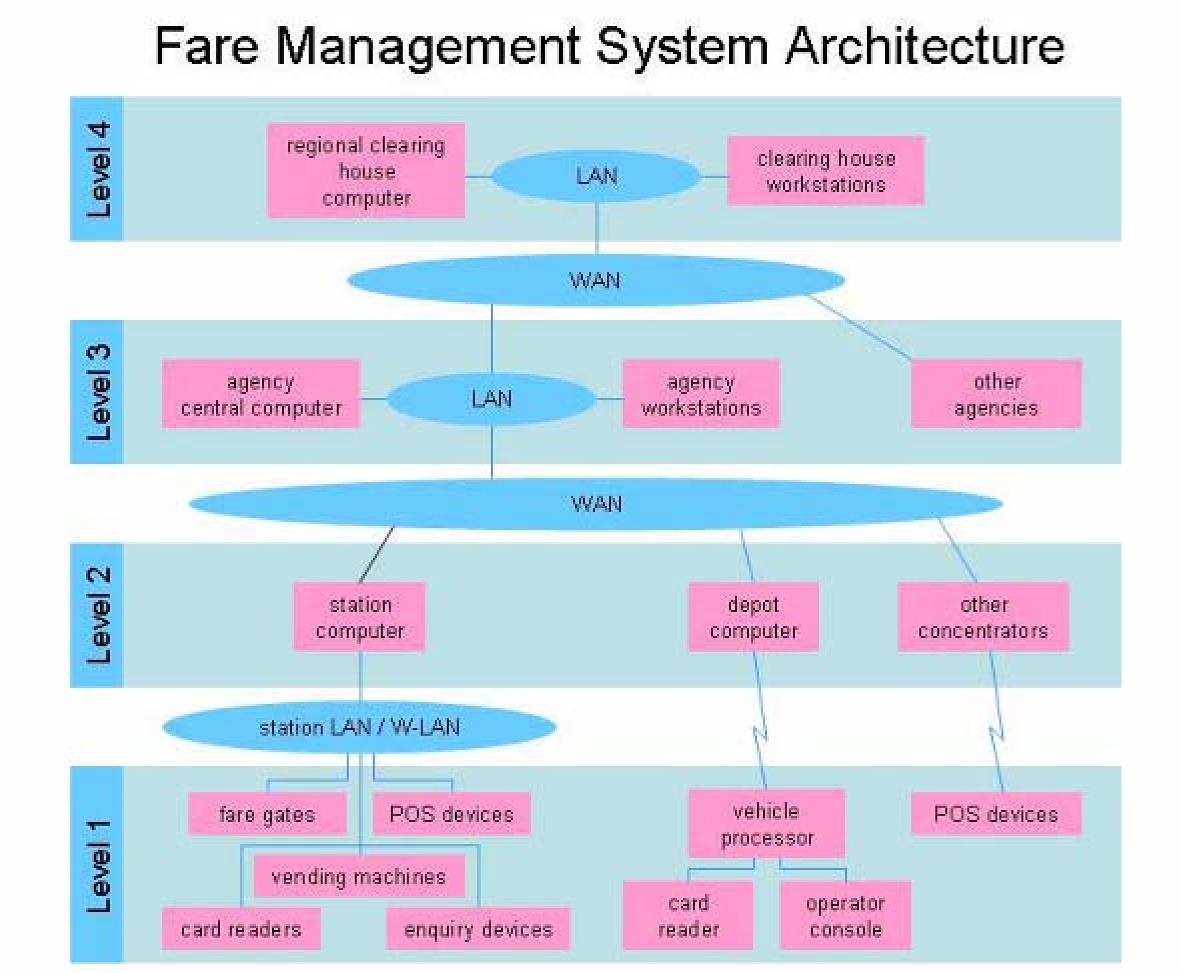

Figure 16 Fare Management System Architecture

The fare system architecture shown in Figure 16 includes four distinct levels:

- Level 1 represents the front-end device tier. These devices perform card reading and writing, and card issuer functions. The technologies are deployed on vehicles, at station turnstiles, and at other fare payment and sale points where patrons purchase fare media or present fare media to readers. Examples include ticket vending machines, balance enquiry machines, onboard driver consoles, card validators, fareboxes, and fare gates/turnstiles.
- Level 2 is the station or depot-level computer tier. At this level, fare transaction data are collected and aggregated from the field and vehicle devices. The data are then forwarded to the agency's central computer. Maintenance data, such as equipment availability, may also be forwarded. Data can flow in the other direction as well, such as hot lists or fare table changes from the central computer to the front-end devices.

- Level 3 represents the agency's central computer system that collects and processes the station- or depot-level computer data.
- Level 4 is the Clearinghouse and Regional Service Center tier where transactions are cleared and settled in multi-organization fare systems. Reporting and management functions for a multi-organization fare system also take place at this level. The functions performed at this level are governed by the business rules agreed to by all system participants.

Fare products such as cash, tickets, smart cards, magnetic stripe cards, and other media are not shown in Figure 16, but are defined as Level 0. Advanced networking capabilities and robust servers are critical components of the infrastructure needed to support all levels of an electronic fare payment system.

Electronic fare payment systems can provide a range of potential benefits to transit agencies and their customers, including simplifying fare payment, increasing customer convenience, reducing boarding times, improving revenue security, increasing information about ridership and fare payment trends, and potentially eliminating the acceptance of cash, coins, and tokens. Contactless smart card readers can reduce maintenance and equipment downtime due to the lack of moving parts associated with solid-state electronics. Equipment reliability rates increase and there is a potential for reduced maintenance costs (e.g., a contactless smart card reader is less maintenance intensive than a mechanism to accept and transport tickets).

Electronic transactions also facilitate data gathering and analysis because of the additional fare and ridership information obtained electronically (e.g., the time, location, and type of each transaction). Analyses and reporting tools are needed to verify, format, and query this information for it to be accessible and valuable to the transit agency.

There are a number of newer and emerging technological changes and integration options currently offered by suppliers that can accommodate both open and closed fare systems. Examples include fare transaction machines that can read and write to multiple media and fare products, fare box add-ons that handle contact and contactless cards, and ticket vending machines with bigger, more flexible screens and menus. Electronic screens and menus can more easily present changing fare media options than equipment dominated with fixed buttons. New fare products, as described in Section 4.3, have also allowed new fare payment and incentive options. In general, most fare technologies have been available for several years, but the deployment of these technologies has been relatively slow due to the length of time needed to plan, fund, procure, implement, and test them.

Some interesting applications of fare technology are discussed below and include:

- Multi-application smart cards (e.g., paying fares and gaining building access);
- Using fare technologies to simplify regional fare payment for both customers and riders;
- Partnering with private sector participants;
- Creating new marketing and incentive programs; and
- Emerging paratransit applications.

4.2.1.1 Electronic Fare Collection Systems to Solve Complexity and Provide Integration

Some of the newer options for electronic fare collection systems can help simplify regional fare payment issues for travelers. Regional travel issues have arisen because suburban sprawl and the diffusion of employment sites have created more complex travel patterns across transit service provider boundaries. New customer travel requirements demand that integration of transit services be improved to better serve these changing needs. Today's travelers move more often between different service providers. They also move between different modes such as bus, rail, and paratransit. In these chained trip situations fare payment can be expensive, complex, and confusing. In some areas where passengers use multiple transit operators and different modes to complete their travel trips, transit operators are moving away from multiple, nonintegrated fare collection systems to systems that only require use of a single fare product. A common progression is for a group of regional agencies to start with individual agency fare products. The next move typically involves a regional magnetic stripe fare product, followed by use of contactless smart cards across the region. A common electronic fare collection infrastructure can provide efficiencies to each of the various regional agencies and help improve overall customer service.

4.2.1.2 Smart Card-Based Fare Systems

Smart card based fare collection systems provide a good opportunity to facilitate multimodal trip making, which can be complex. A smart card is a more secure and flexible option than a magnetic stripe card because of its embedded microprocessor and memory that allow more complex data interactions with the read/write device and more secure encryption. Smart cards can allow travelers to pay for multiple modes of transportation regardless of whether the service is administered by one agency or by multiple agencies within a region. In addition, the better memory and the processing capabilities of a contactless or proximity smart card-based system, the easier it is to incorporate other nonfare applications such as employee credentialing, building access, or accepting smart cards issued outside the regional transportation system such as by a financial institution.

The level of integration in smart card fare systems that serve multiple transportation agencies can vary greatly. The simplest level of integration involves the use of a common card with fare payments occurring solely from an "electronic purse."[59] In this simple integration model, agencies can have independent fare structures. At a more complex level, fare structures and transfer policies may be coordinated within the region. In this case a customer may use the same fare card with different fare payment options to obtain transportation services from a variety of operators and modes.

To effectively integrate fare payment systems with a single payment device, consensus between service providers must be reached on a variety of program levels such as deciding transfer policies, fare policy, card features, revenue reconciliation, clearinghouse and customer service requirements, and performance specifications for cards and readers.

Critical to the success of an integrated fare payment system is ensuring that customers can easily add value to their smart card, which is often referred to as reloading or recharging the card. When a customer reloads their card they typically add funds to the electronic purse, and/or purchase another fare payment option such as using the card as an unlimited ride pass. A transit agency can increase the number of locations and methods by which customers can reload their smart cards by integrating their cards with other reload networks. In addition to reloading cards at vending machines and customer service offices, options for recharging include ATMs, "intelligent" public phones, hand-held devices, the Internet, kiosks, onboard the vehicle, and at fare gates/turnstiles.

4.2.1.3 Facilitation of New Marketing and Incentive Options

Electronic fare collection system components, such as magnetic stripe cards, smart cards, and better back office analysis and reporting systems have enabled new marketing opportunities and ridership incentive options. In addition to flat cash fares, a wider variety of other fare pricing options are possible. Examples include unlimited ride cards for a specified time period, employer subsidies, and bonus trips for frequent riders.

4.2.1.4 Systems with Non-Transportation Agency Partnerships

Public transportation smart card applications can benefit significantly from partnering with private sector commercial applications or other government agencies. For example, partnering with a bank, a credit card, or a telecommunications company may result in sharing the development costs of the smart card infrastructure. Multiple card applications also increase the attractiveness of the card to the customer and help increase market penetration.[60] In Europe, for example, a common electronic purse can

[59] An "electronic purse" stores prepaid monetary value.

[60] The smart card is accepted and used by more people in more markets, such as transportation, retail and municipal services.

be used by consumers to purchase goods at participating shops or when using public phones. In another example, some combined or "open system" smart card applications have chosen to keep the commercial activity separate (sometimes in a second electronic purse) from the transit application. In Finland, some smart cards combine transportation applications with municipal applications such as parking, libraries, and public swimming pools.

Advances in smart card and electronic fare payment system technology make these partnerships possible. It must be noted, however, that many of the issues that need to be resolved in a multi-application environment are not technical, but are instead institutional and operational in scope. These issues lie in the economics of the business case and in the operating rules between the entities, and can be quite complex and delicate matters to resolve. For instance, a key stumbling block between the transportation and financial industries is the high cost of transaction fees charged to a transit agency for accepting a bank-issued card for payment of fares at a fare gate, a turnstile, or on a bus. These fees are typically very high relative to the low value of the transaction. Issues such as this must still be resolved even after the technology barriers are removed in a multi-application environment.

4.2.1.5 Paratransit Applications

Electronic fare systems can be designed to support a range of paratransit and human services transportation provider needs. The payment of fares and the establishment of eligibility must be a simple process for the paratransit passenger when boarding the vehicle. However, requirements for billings and payments can get complicated. For example, some customers may be eligible for a variety of services that are funded by different organizations at different funding levels. These customers may also take trips that are not eligible for full reimbursement.

Given the complexities associated with eligibility and payments processes, automation to support fare payment can often provide a range of benefits that include increased speed of reservations, boardings, and back office processing, as well as improved accountability, tracking, and accuracy of the data. In general, the automated support for fare payment in the paratransit arena is closely tied to the general paratransit operations system software.

4.2.2 State of the Art

Electronic fare collection systems with state-of-the-art components and features are being demonstrated and implemented across the U.S. Some of the systems will be described here, in Section 4.3 on Fare Payment Products, and in Section 4.4 on the Clearinghouse/Regional Service Center.

4.2.2.1 LACMTA

The Los Angeles County Metropolitan Transportation Authority (LACMTA) continues to upgrade its fare collection system over time, including implementing a universal electronic fare payment system for its bus and rail systems. Currently, the agency offers a regional EZ transit pass good for travel on Metro Bus, Metro Rail, and 20 additional transportation carriers.

LACMTA is also in the process of implementing a multifunction contactless smart card system. Approximately 10,000 LACMTA employees are using identification badges that provide not only transit access via a smart card interface, but also building access/security, logon for their maintenance system, and vehicle logon for bus operators. Eleven regional transit providers are currently using LACMTA's technical specification as a regional standard, and have signed contracts to obtain similar equipment. LACMTA is about to select a vendor to design, build, operate, and maintain a regional clearinghouse.

Another innovative feature of the system is the single-point logon for the bus operator, who will only need to log onto the farebox. The farebox then passes on the appropriate information to related "smart bus" system components such as Automated Passenger Counters (APC), Computer Aided Dispatch/Automated Vehicle Location (AVL), and next-stop annunciators. This feature makes the logon process easier for the operator, saves time in starting the bus service, and improves logon accuracy for a range of ITS onboard systems.

In 2005 LACMTA opened the Orange Line, the first bus rapid transit (BRT) application that will use only a smart card for fares (i.e., no onboard farebox for collection of cash). Rather than logging on to the nonexistent farebox, the bus operator will log on to a SmartMDT (i.e., Mobile Data Terminal). The Orange Line will operate similar to a proof-of-payment rail system. Currently, the system is operating only with prepaid paper media. The agency issues Proof of Payment tickets from Ticket Vending Machines (TVMs). When fully operational, TVMs will be able to issue smart cards and load products to new and existing smart cards. Paper tickets will continue to be available to the occasional rider and for patrons who do not have smart cards. Passengers with cards simply validate their cards at Stand Alone Validators (SAVs) to enter the paid area of the station and board the bus. Fare inspectors will validate cards using a Hand Held Validator (HHV). Combined sales data and card usage data will provide LACMTA with important information regarding travel demands in Los Angeles County.

4.2.2.2 ORANGES

The Orlando Regional Alliance for Next Generation Electronic Payment Systems (ORANGES) completed a field operational test that became the first transit fare collection project in the U.S. to combine multiple payment applications (toll, transit, and parking) into a single, non-cash, payment media. The ORANGES limited-scale field operational test was a joint effort of the Central Florida Regional Transportation Authority (LYNX), the Orlando-Orange County Expressway Authority, and the City of Orlando, in conjunction with the Federal Transit Administration (FTA) and private sector companies.

ORANGES demonstrated the use of a single smart card to pay for services at selected locations of the Orlando-Orange County Expressway Authority's toll road system, LYNX's fixed-route bus system, and several of the City of Orlando's parking garages. The ORANGES card carried cash in electronic form that was accepted at all three agencies, stored toll account information, and contained the full range of prepaid 7-day and 30-day transit fare offerings. Each agency managed its program independently with the settlement of funds between the organizations occurring at a single clearing source. The demonstration project has ended. An evaluation of the project was completed in 2004 by the US DOT/Volpe National Transportation Systems Center.[61]

4.2.2.3 San Francisco Bay Area

In February 2002 the Metropolitan Transportation Commission (MTC) and six San Francisco Bay Area transit agencies introduced the TransLink[62] regional fare payment system. The TransLink smart card system continues to be implemented in the nine-county region with a growing number of transit partners. The card will be used for payment on all Bay Area buses, trains, light rail lines, and ferries. One of the innovative aspects of the TransLink smart card is its capability to provide card holders with "electronic coupons," which is part of an incentive program designed to reward and promote ridership.

4.2.2.4 Maryland's Mobility Cards

The Maryland Transit Administration's MTA Mobility program was the first paratransit service provider in the U.S. to provide smart cards to its customers. The smart cards serve as identification cards, and facilitate the monitoring of customer eligibility, fare payments, and boardings. The cards have helped the MTA to better evaluate and track on-time performance, and have resulted in easier scheduling and increased customer satisfaction. The logon process for operators has also been simplified because they now

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[61] ORANGES Evaluation Phase I Risk Assessment Report, by US DOT/Volpe, March 11, 2004. www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13966.html.

[62] See www.translink.org.

use a contactless smart card for logging on to the Mobile Data Terminal (MDT) on the paratransit vehicle.

MTA started a pilot Taxi Access[63] project in 2004 for ambulatory mobility-eligible patrons with a magnetic stripe card that resembles a credit card and includes the card owner's photo. In the pilot project, patrons can call for a taxi ride 24 hours a day with no prescheduling with MTA. The card also simplifies the payment process for the mobility patron and administrative staff.

4.2.2.5 eCommerce and Online Stores for Fare Products

Transit agencies are now taking advantage of eCommerce opportunities such as online stores to sell fare products over the Internet and enhance customer convenience. Customers can buy fare products using their home or work computers without standing in line or traveling to a sales location, sales opportunities are not limited by physical store or outlet hours, and recordkeeping is improved. San Diego Metropolitan Transit System, TriMet (Portland, OR), King County Metro Transit (Seattle), and the Chicago Transit Authority (CTA) are a few examples of transit agencies that sell passes, tickets, visitor passes, and other fare-related products over the Internet. Agency policies and procedures need to be developed for eCommerce applications, particularly to ensure secure Web sites.

4.2.2.6 Emerging Trends

4.2.2.6.1 San Diego Metropolitan Transit System (MTS)

In San Diego County, the Metropolitan Transit System (MTS) and the North County Transit District are upgrading their fare systems. By using some of the same contracts, the agencies are moving toward a contactless smart card system for their buses, the San Diego Trolley, and the Coaster Commuter Train. Passenger convenience is increased by eliminating the need to buy new passes every month, by having a choice in types of fare products to load onto their smart cards, and by eliminating the need for different payment mechanisms for the various transportation providers. The new systems also benefit transit agencies by providing accurate and timely revenue and data. It is anticipated that fare recovery will increase and the potential for fraud will decrease. Smart card distribution and use will begin in 2006, with a full rollout of the smart cards expected by late 2007.

As with the LAMTC example described above, the MTS fare system will also feature a single point of signon for the bus operator. Tests of this innovative feature have been completed, with implementation expected late in 2005. In this application the bus

[63] Information on Maryland Transit Administration's Taxi Access program for MTA Mobility participants can be found at: www.taxiaccess.org/.

operator logs into the fare collection system and the pertinent information will be passed to the Computer Aided Dispatch/Automated Vehicle Location (CAD/AVL) system via a standard J1708 communications network connection from the farebox.

4.2.2.6.2 Utah Transit Authority (UTA)

The UTA is planning to upgrade its fare systems over the next few years and will have a pilot project in 2006. UTA's vision for contactless fare payment has several elements that include:[64]

- Integration and interoperability with the broader electronic payments world;
- A "Smart Bus" communications system with a single logon and control of all electronic devices. It is intended to be an internally designed, non-proprietary system with an open architecture using off-the-shelf hardware and software;
- Collecting GPS location data at boarding with the fare payment information;
- UTA Fare Card with its own application that can also be licensed to third parties (e.g., universities, ski resorts, banks);
- Broad distribution of limited-use cards for visitors and infrequent or cash riders; and
- An incremental, phased, and collaborative approach.

The UTA is planning to begin its pilot project on its UTA Ski Service using ISO 14443 compliant contactless readers on 40 ski service buses. One of the benefits of the pilot project will be to improve UTA's fare collection and revenue management for riders who previously flashed their ski passes or resort employee ID cards to ride the bus. The project is also intended to test payments via new contactless MasterCard, Visa, and/or American Express cards with UTA serving as a merchant.

In addition to the emergence of more multimodal and regional fare systems that support bus and rail, innovative fare collection systems are being planned for paratransit and rural transportation service providers. Some emerging examples are included below.

4.2.2.6.3 Northern Shenandoah Valley (NSV) Public Mobility Program

The NSV Regional Commission Commuter Bus Smart Card Pilot project has the following three goals:

- Demonstrate the interoperability of an electronic fare medium in a largely rural region, and among human service and public transportation providers;
- Demonstrate the impact of such fare medium in planning, operating, and administering mobility services for transportation-dependent individuals; and

[64] From October 2005 presentation titled "UTA Approach to Electronic Fare Collection" by D. Craig Roberts.

Document the value of an electronic fare medium in managing entitlements for constituents who are disabled, older, and economically disadvantaged. [65]

The proposed pilot will be implemented with buses that provide daily commuter services through the Regional Commission's Valley Commuter Assistance Program. The public-private partnership will equip these buses with AVL, mobile data terminals, and contactless smart card functionality to track and verify each trip and individual trip segment. The rationale for using a smart card is based on two critical customer considerations:

Incorporation of restrictions on the type and amount of consumer information that can be provided per the Federal Health Insurance Portability and Accountability Act (HIPAA).[66] The card must have the necessary level of security to preserve protected personal and medical information; and

Consumers who use the card must have physical or cognitive disabilities that limit their capacity to manipulate a card that requires either swiping through or insertion into a slot.

The key institutional requirements are divided into three categories:

Client (rider) identification;

Special needs driver notification; and

Trip purpose and segment information.

The Mobile Data Computers will be supported by wireless communications and will "read" consumer information from the smart card, including "special needs" and emergency contact, and then display that information for the driver.

Figure 17 includes a diagram from the NSV project description that shows the smart card reader-coordination system interface.

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[65] From "Northern Shenandoah Valley Public Mobility Program," Gregory Cross, Program Manager, October 2005.

[66] Federal Health Insurance Portability and Accountability Act.

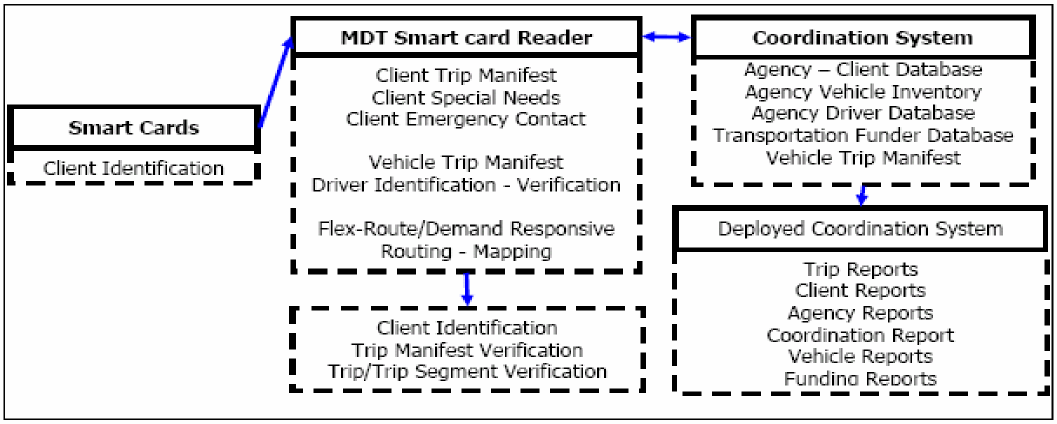

Figure 8: Smart Card – Reader – Coordination System Interface

Figure 17 Northern Shenandoah Valley Smart Card Interface

4.2.2.6.4 Capital Area Rural Transportation System (CARTS)

The Capital Area Rural Transportation System is planning to implement a magnetic stripe RideCARTS card to support their rural transportation system, which provides services for travelers in nine Texas counties surrounding Austin, the state capital. The RideCARTS card will become the single fare media that supports all passengers, whether their fare is paid individually or by a third-party purchaser.

The intent of the card program is to combine data and fare collection into one instrument and to streamline the accounting and collection for both, while at the same time providing ease of use by its customers, both individuals and institutional purchasers (i.e., human service agencies, local governments, etc.). It will also serve as the platform to facilitate paperless, personless reporting for the disparate data needs of purchasers of service, thereby reducing labor-intensive data extraction and paperwork for CARTS. Further, the goal is to promote a seamless fare relationship with Capital Metro, the metropolitan transit authority also headquartered in Austin, Texas.

The Ride CARTS card will have an electronic purse that can be reloaded over the phone or Internet. For paratransit customers, the system is intended to work in conjunction with a Web-based tool that facilitates screening the eligibility of clients, planning trips, and managing trip data. When a paratransit customer boards the vehicle, they will swipe their card and the predetermined cost of the trip will be deducted from their card's electronic purse.

The CARTS fare system will also be designed to accept the Lone Star Card issued by the State of Texas as a Medicare-related electronic benefits card. Users of the Lone Star

Card will swipe their card when they get on and off the transit vehicle to facilitate a behind-the-scenes fare payment process (no value is deducted from the card). The data collected as a result of the card use, such as arrival times and trip distances, will significantly streamline the various reporting requirements. Eventually the electronic purse on the card will make trip payments, but this will require additional work by the Texas Department of Transportation that is not within the scope of this project.

4.2.2.6.5 Other

As part of the Puget Sound Region smart card project, the Washington State Ferry system with assistance from its vendor is developing a mobile Fare Transaction Processor consisting of a portable hand-held unit that will serve as a fare vending, fare loading, and fare verification device.

There is also some exploration occurring in the area of using cell phones to make small purchases called "micropayments." This form of m-commerce, short for Mobile Commerce, involves commerce over wireless devices that may be extended to transit payment applications. The concept is being explored as a payment option that has the potential of being less expensive than using a regular credit card with its high transaction fees.

4.3 Fare Payment Products (Media)

4.3.1 Technology Description

Magnetic stripe cards for electronic fare payment (read-only and read/write) are still extensively used throughout the transit industry. Credit cards are used to purchase fare media, but have not gained the wide-scale acceptance of fare cards because of their high transaction processing fees. Additionally, their format is not standard in the transit industry and would require a massive retrofit of legacy systems that have been using thin flexible magnetic stripe cards as well as Edmondson magnetic tickets. Smart cards are slowly being implemented in the U.S. as compared to the faster rate of acceptance in Europe and Asia. Limited use smart cards are also starting to emerge in the U.S. market. Because of the lead time necessary to thoroughly test and deploy new electronic fare media, it is not unusual to have several types of electronic fare media in use at the same time at a transit agency or in a region. For example, if a transit agency is switching from a magnetic stripe card to a smart card, it may take months to retrofit all buses with the new fare equipment. As a result, some modes or routes may have the new system while others continue to operate with the old system until it is replaced.

The term "smart card" covers a range of cards that use different standards and have different capabilities. Contactless smart card technology relies on a secure microcontroller (or equivalent intelligence), internal memory, and a tiny embedded antenna that communicates with a reader, typically through a contactless radio frequency (RF) interface. Most new cards (memory logic and integrated circuit chip cards) are using the ISO 14443 standard, which is being adapted to support limited-use smart tickets.[67] Smart cards may also be hybrid cards that have two chips and support both contactless and contact uses, or combi-cards that allow one chip to be accessed by either a contact or contactless interface. Additionally, some cards are emerging that support both magnetic stripe and smart card functionality. A good starting point for obtaining additional information about smart cards is at the Smart Card Alliance's Web site at www.smartcardalliance.org.

Some of the new, innovative smart card applications support multi-applications such as different fare types and structures, different agencies, different modes, and other activities such as parking, building access, security, identification, and logon functions.

4.3.2 Changing Environment

Unlike Europe and Asia, credit card issuers and the retail sector in the U.S. have traditionally been slower to adopt smart card technologies. The environment here, however, is finally starting to show some significant changes, especially with respect to possible transportation partnerships with bank card issuers, credit card issuers, retail merchants, and vendors.

In 2005, the contactless payments market had multiple card issuers announce rollouts of contactless cards. Issuers and merchants targeted 8–10 major markets in 2005,[68] with many more to follow. In addition to the card issuers, many of the top national and regional retailers have either enabled, or are in the process of enabling, their point of sale (POS) systems to accept contactless payment cards.[69] Some of the advantages to the retail industry mirror those seen in the transportation sector including speed, convenience, lower costs resulting from fewer requirements to handle cash, improved operational efficiencies, and reduced maintenance required by contactless readers. This change in acceptance of smart cards will facilitate the ability of transportation agencies to develop multi-use smart card fare payment systems.

4.3.3 State of the Art

The use of contactless fare products is state-of-the-art in the U.S. The LACMTA (Los Angeles) has implemented a state-of-the-art, multifunction, contactless or proximity smart card for its employees, which was also described in Section 4.2 when the overall

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[67] Crotch-Harvey, Trevor, "Limited Use Smart Tickets," APTA Fare Collection Workshop, Oakland, March 23, 2005.

[68] www.smartcardalliance.org/alliance_activities/who_what_why_contactless_payments.cfm.

[69] www.smartcardalliance.org/pdf/alliance_activities/Contactless_Payments_Position.pdf.

fare system was discussed. The smart card system will eventually be used by most of the regional transit service providers' employees and their customers.

Washington Metropolitan Area Transit Authority (WMATA) recently launched a three-year pilot project with a bank, where passengers can receive a MasterCard with a smart card chip that allows them to pay fares, parking, or make purchases with the same card.[70]

The Chicago Regional Transit Authority (RTA) has two smart cards in use: the Chicago Card and the Chicago Card Plus. The Chicago Card offers touch-and-go boarding, a $1 bonus for every $10 of added value, and fare protection. The Chicago Card Plus offers numerous benefits that include fare choices, bonuses, online reloading over the Internet, quicker boardings, account management, and protected fares. With protected fares, if a Chicago Card Plus is lost, stolen, or damaged, the customer can go online or call the CTA to report the problem. A replacement card will be issued and the balance in the account at the time the CTA was notified of the theft or loss will be restored.

There are several agencies demonstrating Limited Use (LU) Smart Tickets. These low cost, throwaway, and sometimes reloadable cards are based on Radio Frequency Interface Device (RFID) technology. The LU smart ticket, similar to the smart card, contains a chip attached to an antenna that is embedded into a paper-coated Polyethylene Terephthalate (PET) card. It has limited memory and no processing. The cost of these cards is lower than typical smart cards since they are physically less robust with somewhat less functionality. These limitations are not expected to be a problem since the expected period of use for the LU smart ticket typically ranges from a day to a month. The LU smart ticket is deployed in several cities in Europe including Paris, Capri, and Porto, among others, and may soon be deployed at MARTA in Atlanta.

4.3.4 Emerging Trends

The Massachusetts Bay Transportation Authority (MBTA) is introducing the "Charlie Card," a contactless, stored-value smart card as a part of its upgraded automated fare collection system. Additionally, the Port Authority of New York and New Jersey is working on a smart card pilot project for the Newark AirTrain and New Jersey commuter rail systems.

King County Metro in Seattle is still in the process of implementing a regional, multimodal contactless smart card system. The system will include a driver display unit that will serve as a single point of communications and logon for various onboard systems such as fare collection, AVL, and APC. For the fare collection system, all of the

[70] www.publictransportation.org/media/release050908.asp.

back-office systems are built, but the Beta test of the cards onboard the vehicles will not start until early 2006. Some of the innovative features of the smart card system include:

- "Right to Ride" with no actual value stored on the card. Instead, the card will store account information for a participating employer that provides transit subsidies to its employees;
- The "Flat Rate" program, which reduces the administrative burden for employers that provide transit subsidies to their employees. The employer agrees to a flat rate for a certain period of time (e.g., six months) to pay KCM, which in turn pays for the riding activity of its employees. The smart card fare collection system tracks employee ridership, and the data is used to adjust the flat rate for the next billing period;
- Each participating employer can have secure access to a regional Web site to monitor and change elements within their fare payment program with KCM. The flexibility of the smart card, in conjunction with the Web site tools, provides many benefits such as increased convenience, increased ridership, decreased risks for employers, decreased administrative effort, a more cost-effective way to market transit via a wholesale employer-provided subsidy, and more data to fine-tune budgeting, communications, and marketing; and
- A disposable card that can be used for tourists or shorter-term ridership that will not be reloadable or registered.

4.4 Clearinghouse/Regional Service Center (CH/RSC)

A regional fare system's Clearinghouse or Regional Service Center provides a wide range of functionality. The functions may be allocated to one or several organizations. For the purpose of describing the technologies and functions, the guidelines presented in the *Major Business Issues* document published by UTFS describes that "the function of the CH is to provide the regional system with clearing, settlement, and the associated financial reports and management information."[71] When the CH begins to offer additional services, it may more accurately be described as a "regional service center" (RSC) rather than a "clearinghouse."[72] Depending on the size and scope of responsibilities and the agreement between regional partners, the institutional framework for establishing the Clearinghouse and Regional Service Center may be implemented as a single entity or two separate organizations.

There are a number of regional payment systems currently deployed, with many more in the planning and development stages. Almost every major metropolitan region is investigating the implementation of a regional payment system to provide transit riders

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[71] UTFS Task Force Financial Management Committee Business Process Work Group, "The Major Business Issues in Establishing and Operating Regional Transportation Payment Systems and Clearinghouses." APTA, Version 2.01, edited September 20, 2004.

[72] From "Major Business Issues," p.14.

with a seamless and convenient way to travel across the region using a single fare product. The ability to implement these regional payment systems was enhanced through the advancement of automated fare collection systems using smart cards. The CH/RSC model is based on the need to pool, settle, allocate, and distribute ridership revenue among regional carriers in a secure, fair, and equitable manner. The regional agreements may be extended to create economies of scale in the procurement, deployment, and maintenance of automated fare equipment, as is the case with WMATA. The importance of the institutional framework cannot be understated, as asserted by the New York MTA:

> While riders will be most immediately affected by the fare media and readers that are chosen for the system, the selection of an institutional framework supporting a fare collection system is perhaps of greater importance to the success of the system than the choice of hardware to be used.[73]

The primary functions of a Clearinghouse/Regional Service Center include:[74]

- Funds Pool Management;
- Settlement;
- Funds Distribution Procedures;
- Rules and Regulations;
- Security;
- Reports; and
- Change Management.

Other functions include:

- Card Base Management;
- Fare Policy Management;
- Load Procedures;
- Network and Equipment; and
- Marketing and Branding.

The "*Major Business Issues"* document referenced above is a best practices guideline that describes how to establish and operate a clearinghouse/regional service center. It was developed by APTA's UTFS Financial Management Committee Business Process Work Group. The UTFS document describes the key considerations for addressing business process issues related to establishing a regional transportation payment systems clearinghouse. The document describes original agreements, funding provisions, and governance structures, including ownership, board formation, and membership.

[73] From MTA, p.2.

[74] "From Major Business Issues," pp. 14-39.

Alternative models for operations and management of the clearinghouse are also discussed.

The lessons learned documented in the UTFS Major Business Processes and many publications by the Transit Cooperative Research Program[75] have established a clear, uniform set of guidance documents for public transportation officials to consider when moving toward regional coordination.

The CH/RSA can be a center that is operated in house, by a single transit provider serving in the manager role, or by a contracted third party. There are advantages and disadvantages to the various models. Each of these models has been adapted by different regions. For example, the Bay Area's TranLink® is operated by a contracted third party. CTA operates its own clearinghouse and regional service center functions for its Chicago Card and Chicago Card Plus programs. Similarly, New York City Transit (NYCT) operates and manages the MetroCard, which is used by NYCT and regional transit service providers.

4.4.1 Technology Description

Since the clearinghouse serves the function of a critical data center, the requirements for operating and maintaining a high volume, secure transaction processing data center drive the technology. Accordingly, the technologies associated with the CH/RSA are basic back-office systems such as communication networks, servers, backup storage, and software systems. For the clearinghouse and its technologies to operate effectively, regions have learned that it is important to establish procedures and standards that define service levels, monitoring efforts, and mitigation procedures.

Deployment of the clearinghouse and its associated technologies and equipment typically occurs simultaneously with the procurement and installation of operator fare equipment (e.g., fare boxes/fare gates, validators, balance enquiry machines, card readers), card vending machines, parking devices, computers, and networks for the agency's offices and garages.

4.4.2 State of the Art

The most successful and effective Clearinghouse/Regional Service Centers depend on a well developed and thought out institutional framework supported by technology. To be successful, a great deal of effort needs to be put into the development of a governance structure, and procedures for financial settlement, reciprocity reporting, customer service, and card management.

[75] www4.trb.org/trb/crp.nsf.

Emerging standards in the fare collection area will make the deployment of regional payment systems easier in the future. The technology innovations that support the clearinghouse area are emerging along with the standards. The UTFS standards will facilitate a common glossary and will specify the following interfaces:

- A smart card data format;
- Data message sets from the card reader to the agency central computer; and
- Data message sets from the central computer to the CH/RSC.

One of the first clearinghouse/regional service centers was the TransLink® system in the San Francisco Bay Area. Initiated by the MTC, the effort was undertaken in response to the increased need for seamless travel options throughout the Bay Area following the earthquake of 1989. MTC spent many years developing the original agreements with regional providers. Although MTC staggered deployment of the regional payment system across the 34 regional carriers, as soon as a single operator offered the regional payment method, the clearinghouse needed to be operational.

In 1999 WMATA initiated a contactless smart card program, which went through several stages. A thorough systems engineering analysis was performed and a regional payment system was then proposed. WMATA and its 19 regional partners (in Maryland and Northern Virginia) identified key issues, mostly institutional and policy related, in establishing the Regional Service Center. The service center is responsible for two main functions: clearinghouse activities and customer service (called the Regional Customer Service Center or RCSC). The clearinghouse and customer service center went live in January 2005. At the RCSC, the contractor only performs the customer service center functions, with no authority to provide refunds. The RCSC pools funds from bus, rail, and parking revenue collection systems.

The regional agencies used the cooperative framework of the RCSC to leverage WMATA's automated fare system procurement to purchase fare equipment. This approach helped facilitate card sharing, thereby simplifying the overall system. By sharing a common card and using a common vendor, the following aspects of the RCSC were made possible:

- All participating agencies jointly fund the clearinghouse and customer service center. The fee is paid monthly and adjusted by ridership;
- Fees are apportioned by the amount of service provided;
- An agency's connection to the clearinghouse will be staged, based on their own development and deployment schedules;
- The headquarter's system for each agency will be connected using a common interface (called Data Network Concentrator — DNC) developed by the vendor to the automated clearinghouse. This connection will also act as an audit trail to financial institutions;

The common DNC interface made it easier to administer the clearinghouse functions in a regional setting; and

A major component of the clearinghouse is a database that stores transaction information from all the regional partners. It includes settlement rules and generates a standard file for dispersing the revenue to the appropriate banks that represent the various transit agencies. The function then sends customer service information using a "service interface" to the Regional Customer Service Center.

WMATA and its regional partners sought to ensure that the service interface was non proprietary. As such, they undertook the development of an open interface called SIRS. WMATA determined that the cost of using the clearinghouse approach and regional customer service center for paratransit was too high at the time of the analysis.

4.5 Challenges and Lessons Learned

Moving the state of the art forward in the fare collection field has been a relatively slow process, particularly in the area of regional smart card fare collection systems. Most of the larger regional installations have taken more time than originally planned, and many are not yet fully implemented. Contributing to the problem is the fact that larger systems are expensive because of the large amount of equipment that needs to be purchased, and the extra care needed to protect revenue security.

Some of the issues that have contributed to the slower pace of electronic fare payment implementation are discussed below, including a number of challenges and lessons learned.

4.5.1 Integration and Interoperability

A principal challenge for deployment of electronic fare payment systems is integrating equipment from different manufacturers. Some of these issues arise when different types of fare collection equipment are used within a system; others arise when a region is trying to have a system used by one transit agency operate seamlessly with a different system used by another agency. The issues are significant enough that the Transit Cooperative Research Program (TCRP) recently funded a project on smart card interoperability issues for transit.[76] The project identified several examples of complicating factors, including:

Application of multiple fare-payment systems and technologies;

Transit agencies' different operating needs and fare mechanisms;

Inadequate communication protocols and information exchange among transportation clearinghouses;

[76] TCRP Project A-26, Smartcard Interoperability, Draft Report scheduled to be issued in fall 2005.

Absence of a single application programming interface to foster interoperability; and

Intellectual property barriers that do not allow for open architecture.

Another major challenge has little to do with the interoperability of the hardware and software, but rather with the robustness of the working relationships among the various transit operators in a region. Agency personnel need to understand that technology can only enhance existing manual systems and organizational relationships; it cannot be expected to create them where none had existed before.

4.5.2 Regional Systems

Regional fare systems face additional complications from having to integrate and be interoperable across multiple transportation agencies. Clearly, as the number of participating agencies increases, so does the potential for more issues. These issues have been systematically resolved in a number of regions by advanced planning, a strong commitment to collaboration, effective decision-making procedures, and through a well thought out project architecture and system design.

Functional specifications and contract negotiations for integrated systems take a significant amount of time to be developed. All parties should be involved in each of the various development stages.

The resolution of fare policy issues, business rules, and revenue reconciliation issues should be started very early and in parallel with other requirements and development activities. There are many issues and decisions to resolve, including those as basic as agreeing on common fare category terminology (i.e., agreeing on the ages of children and seniors eligible for discounted fares). Every agency interviewed concurred that this process is very time consuming.

4.5.3 Standards

Since integration and interoperability are such significant challenges to implementing fare collection systems, particularly regional ones, a large number of standards development efforts are ongoing. A characteristic of standards for fare collection is that there are many options and few comprehensive solutions. Additionally, the field of standards has challenges of its own.

There are two efforts underway in the U.S. to generate standards for the fare collection system. The APTA-managed Universal Transit Farecard Standards (UTFS) program, a USDOT funded project, was initiated in 2001, while APTA's Transit Communication Interface Profiles (TCIP) project began developing the fare collection section of its work in 2004. In addition, there are international standards development activities underway with other standards emerging or being deployed throughout the world.

Existing and emerging fare collection standards address requirements for different levels within the overall system architecture. The Fare System architecture, depicted earlier in Figure 4-1, illustrates four levels where standards are currently being addressed. The fifth level, Level 0, is the Media Level where standards for smart cards are represented. A more detailed review of fare collection standards is included in Chapter 2, Integration.

The benefits from the fare collection standards efforts are still emerging. Transit agencies need to determine which of the standards are appropriate for their particular applications.

4.5.4 Equipment

There are numerous lessons learned regarding electronic fare payment equipment from deployments of smart card-based systems:

- A number of transit agencies have reported that fare equipment maintenance can present challenges.[77] Some problems stem from proprietary or more complex electronics, the need for new training, trying to do maintenance in the field on high-revenue routes, and dealing with dirty, bent, or damaged tickets.[78] The equipment must function properly to maintain customer satisfaction (i.e., for the customer to buy fare media and board the transportation system) and for the transit agency to collect needed revenue and data. Maintenance standards and response time requirements need to be specified in advance.
- When rolling out new systems there is a time period when both the old system and the new system and their fare media must be maintained. This dual maintenance can be a significant burden on transit agencies, both operationally and in terms of cost of maintaining a dual system.
- When project planning allow ample time for equipment replacement or fare system upgrades as they tend to require extended time periods to successfully complete. Realistic project planning reduces the window of high risk with old, unreliable equipment.
- The process of getting multiple vendors, both of legacy and replacement equipment and systems, to work together to produce an entire working system often requires additional time and effort. Time for these likely delays should also be included in the project plan.

[77] As reported in the "Assessment of ITS Deployments - Draft Final Report," Technology Solution Providers, May 2005.

[78] www.toronto.ca/ttc/pdf/fare_collection_report_2000.pdf.

Ensure that smaller, older vehicles have the wiring, battery power, and communications capacity to support the additional electronics that will be added to the vehicle.

Fare products and equipment can be rendered obsolete by manufacturers, resulting in unavailable or unsupported products. For example, the type of smart card used in the ORANGES demonstration was discontinued by the manufacturer.

Transaction speed is important, particularly in large, highly populated metropolitan areas. For example, the maximum amount of time to read a fare product, determine if it is a valid potential entry, and open a fare gate is usually set at 1.0 to 1.5 seconds. A number of systems operate even faster. Appropriate requirements for the total transaction time must be included in the system specifications.

4.5.5 Other Challenges and Lessons Learned

Some other miscellaneous challenges and lessons learned regarding electronic fare collection systems include:

When building systems for paratransit and human services providers the organizations may have fewer on-staff technical resources, which often places a stronger focus on client issues rather than transportation and technical issues. As a result, some categories of requirements and specifications may be better articulated than others. The project team will need strong technical support to assist with defining the full range of requirements.

The cost of smart cards is still somewhat of a barrier, particularly for limited-use applications, such as for tourists and other infrequent riders. Even limited-use cards have still not achieved a low enough unit cost to effectively address the single journey issue.

A number of business and technical issues can be barriers to developing partnerships with retail or financial partners. Some of the barriers will lessen as more standards emerge to reduce equipment incompatibilities and retrofitting costs. Overcoming other barriers simply requires negotiations skills and the initial selection of a relatively compatible partner organization. These barriers may include selection of compatible standards, cards, operating systems, security approaches, methods to upgrade, and point of sale terminals. Another issue involves potential changes in fraud exposure and liability. That is, determining who is responsible for fraud and liability issues with respect to multiple functions on a card.

Rights to the use of intellectual property such as equipment interfaces, source code, or other proprietary information must be addressed in the agreements with contractor(s). The inability of public agencies to share key technical details with all contractors or with future contractors will inhibit competition in electronic fare collection system procurements. The inability to share these technical details with regional partners will inhibit coordination and interoperability.

Some of these barriers and issues have been resolved in various ways in other countries, including numerous examples found in Europe. Finland, for example, developed national smart card policies in the mid-1990s to facilitate standardization and the broad use of smart cards in transportation and municipal applications. Most agencies indicate that the biggest advantages from smart card fare collection systems occur when there are multiple uses for the card.

Ultimately, having a clear vision of what is expected from an electronic fare collection system is important. Since vendors serve a range of markets with different needs, it is essential to clearly articulate your agency’s overall vision and corresponding systems requirements.

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Chapter 5 Traveler Information

5.1 Introduction and Technology Overview

ITS Traveler Information systems are vital for both customers and transit agencies. For customers, the systems help them learn about and use the various public transportation services offered. For transit agencies, Traveler Information systems lessen the burden on staff who provide customer information, and the agency's overall telephone system. In addition, transit personnel frequently use the information systems themselves to locate information when working to improve transit services. Other benefits include reduced incoming phone calls seeking transit information, shorter phone calls, fewer dropped calls, increased ridership from new and existing patrons, increased customer satisfaction, less e-mail correspondence, and faster access to service information when researching problems.

Data provided by Traveler Information systems can consist of relatively static data elements such as schedules and fares, or more dynamic elements such as estimated real-time arrival times, route delays, and traffic flow conditions. The accuracy of the data provided to the public is essential and depends on constantly updating a number of integrated data sets. Those data sets might include scheduled service, changes to scheduled service, fare tables, special events, service disruptions, bus stop names and locations, landmark names and locations, street names and alternative names, addresses, and transportation network information including private roads, walking paths, and other modal paths. Travelers may need this information for trip planning purposes, at trip commencement to verify key pieces of information, or while enroute (particularly if incidents or service disruptions occur).

With the advent of regional trip information systems that span multiple jurisdictions, the resources needed to integrate these data sets and keep them accurate become even more challenging. The challenges stem from the fact that regional transit trip information typically requires the integration of dissimilar data sets from multiple agencies to support multi modal and multi agency trip planning and transit information. Examples of the data needed for regional trip planning applications include interagency and intermodal transfer locations, multi agency transit center walking directions, regional consistency in naming and locating services (including stops and stations), a common set of landmark and street names, a common base transportation network, and location references. The use of standards and established regional procedures is necessary to maintain and improve data quality.

Because of the difficulties faced by transit agencies in developing, managing, and maintaining the data for traveler information systems, a section titled "Transit Trip

Information Infrastructure" is included in this chapter. It highlights some of the critical information infrastructure elements identified by transit agencies regarding state-of-the-art systems. By having an effective infrastructure to support traveler information systems, it is easier to provide more information options, information products can be more cost-effectively produced, operating impacts are minimized, and investments in software and data can be leveraged.

5.2 Transit Information Systems

5.2.1 Technology Description

Table 8 summarizes the various types of Traveler Information systems used in transit today. The systems vary in several ways. The information provided can be static or real-time information. Many of the systems provide pre-trip information, but an increasing number of them are providing information onboard the vehicle, in transportation terminals, or on personal information devices such as cell phones. New information products and services are also being provided such as customized timetables or interactive maps.

Traveler Information systems are moving away from "stovepiped," stand-alone vertical systems to more integrated systems that make a variety of services available through multiple "channels." Examples of channels include Interactive Voice Response (IVR), data tables or interactive maps on the Web, dynamic message signs at transit stops or on the vehicle, voice annunciators, or Instant Messages to cell phones or personal digital assistants (PDAs). An emerging capability is to reuse some system modules or services (e.g., a dynamic timetable generator) to provide similar pieces of information (e.g., planned schedule data and real-time estimated arrival times).

Some of the more significant advances have occurred in the area of integrated regional traveler information systems. In particular, the advances have been through 511 telephone information systems and technology infrastructure improvements that allow better and easier access to transit data.

Table 8 Types of Traveler Information Systems

Subcategories	Description	Example Technologies, Business Processes, or Software
Transit Information Systems	Addresses the many ways of obtaining traveler information including pre-trip, personal, in-terminal / wayside, and in-vehicle information systems. Pre-trip systems include information obtained before departing on a trip. Can be static and/or real time, and may include transit routes, maps, schedules, fares, park-and-ride lot locations, transit trip itineraries, paratransit information, special events, service disruptions and revisions, etc. Channels that disseminate pre-trip information include the telephone, Internet, electronic kiosks, fax machines, television, personal systems (see below), etc. Personal systems include information accessed through PDAs, cell phones, and laptop computers prior to, or during, a trip. In-terminal systems provide arrival/departure information for buses/trains at bus stops, terminals, train stations and platforms. Information is displayed on monitors, variable message signs, sign boards, passenger information displays, and/or electronic kiosks. May provide static (scheduled) or real-time information. In-vehicle systems provide automatic visual and/or audio announcements on transit vehicles. Typical announcements include next stop, major cross road, transfer point, landmark, and destination information. Additional information, such as public service announcements and advertisements, may be provided at other times. Complies with Americans with Disabilities Act (ADA) requirements.	Pre-Trip - Customer information systems for trip planning - Customer call centers - Web - Provision of schedules and next bus information through a variety of channels - May include incident notification, transit vehicle arrival alert, or other subscription information - Route maps and bus stop locations Custom travel profiles and subscription services such as real-time alerts and static schedule downloads Personal Information Systems - PDAs - Laptops - Cell phones In-Terminal Information Systems - At stops and stations - Also includes facility status information (e.g., elevator/ escalator outages) - Infrared signage (e.g., talking signs) allowing sight impaired customers to orient themselves within the station environment In-Vehicle Information Systems - Annunciator and signage provided inside and /or outside of the transit vehicle Personalized Transit Information - Transit status based on traveler's itinerary, sent to traveler via e-mail or Web page

Subcategories	Description	Example Technologies, Business Processes, or Software
Multimodal Travel Information Systems	Includes the use of any type of traveler information channel (call centers, kiosks, Internet, telephone, cell phones, PDA's, pagers, etc.) to provide real-time and static information on transit, traffic and other modes to enable travelers to make fully informed mode choice decisions both pre-trip and enroute.	- 511 systems - Regional or multi-agency systems - Can include both integrated information and agency specific information

5.2.2 State of the Art

This section discusses state-of-the-art Traveler Information services that are currently implemented at transit agencies. A number of Traveler Information systems that are state of the art are also described in Section 5.3.2, which focuses on the data and information infrastructure advances, and in Section 5.4, which highlights some emerging Traveler Information technology trends.

In recent years, advances in database tools and Web services have facilitated the development of more specific query options for customers and staff. Instead of having to become a skilled user of more complicated (yet more flexible) trip planner tools, customers can use custom applications tailored to obtain explicit information, such as to identify all services available near a given location or to produce customized timetables.

Improvements in Geographic Information System (GIS) tools, Web access and speed, and in interactive Web mapping technologies allow easier and better querying and displaying of geographic data. Transit agencies are now able to provide a variety of different map views and tools to their customers to meet different needs and preferences.

Improvements in the speed and accessibility of wireless communications are changing, and will continue to change, the way in which transit agencies are able to provide traveler information. At some agencies, transit staff and customers can now access information at bus stops and onboard vehicles. The increasingly widespread use of cell phones and PDAs now allows mobile access to telephone information and Web browsers.

State-of-the-art ITS applications discussed below either provide new services to transit customers, employ new dissemination modes or channels, provide answers more clearly through improved formats and representations, and/or provide the information more quickly for transit staff and customers. Advances in Traveler Information also facilitate regional travel, travel across different transit providers, and the use of different transportation modes. Examples of these advances include:

Capital Metro in Austin, TX has improved its paratransit service for both the customers and transit staff through the use of an automated dial-out ITS application that calls clients to inform them of changes in their pick-up times.

NJ Transit (NJT) rail customers benefit from a Web-based station-to-station trip planning function (See Figure 18). The specialized tool is simpler to use for planning rail trips than the general Itinerary Planning system. Other tailored trip planner tools include an option to locate services near a particular location, bus routes by county, and station-to-station light rail schedules.

In August 2005, the RTA (Chicago) announced a new cell phone and PDA accessible Traveler Information Web Site. Called RTA Mobile, the new site can be accessed at www2.rtamobile.com by Internet-enabled cell phones and PDAs. It provides the wireless Internet version of the RTA's Itinerary Planning System. Over time, RTA will add more capabilities to the site. The wireless Web site is anticipated to decrease calls to the RTA Travel Information Center and provide new information options to the traveling public.

Real-time tracking of transit vehicles has become more common. Real-time transit information can be provided over the Internet, via telephone, on the vehicle, and at the wayside. Many of the displays are more attractive and easier to view. For example, real-time bus tracking services that appear on a map are available at TriMet (Portland, OR) via their Transit Tracker service, at King County Metro (Seattle, WA), and Cape Cod Transit (Hyannis, MA). Cape Cod's real-time bus tracking tool serves both fixed route and paratransit service. For their rural service, with longer headways and flag stops, this tool has helped customers know when to go out to the road to flag down the bus.79 In another example, the Washington State Ferry System displays the position of ferries on an Internet map with the assistance of Global Positioning System (GPS) technology.

Estimated arrival times of transit vehicles are displayed at key bus stops and transit centers at a variety of transit agencies. Los Angeles County Metropolitan Transportation Authority (LACMTA) displays estimated real-time arrival times for some Bus Rapid Transit (BRT) vehicles on Light Emitting Diode (LED) display signs located at major bus stations. The City of San Luis Obispo (SLO)

[79] A Transit Cooperative Research Board report titled "Real-Time Bus Arrival Information Systems: A Synthesis of Transit Practice, Report #48," provides an overview.

Transit uses a relatively low-cost approach that involves sending a text message about the bus's expected arrival time via a pager to solar-powered "Smart Transit Signs" at the next bus stop. In Colorado, the Regional Transportation District (RTD) provides estimated arrival times at key locations, on the Web, and via wireless options.

A number of wireless options for accessing transit traveler information are provided by the RTD as shown in Figure 18. Customers can download schedule data to PDAs, register for e-mail updates, call for predicted arrival times of RTD buses and trains, download custom schedules, and navigate to a special Web site designed for mobile phones and PDA browsers to obtain real-time arrival information.

Interactive mapping of transit routes, facilities, and other transportation services has improved and become more commonplace. For example, TriMet has some easy to use, fast, and attractive applications that allow the user a range of specific query and display options. Figure 19 shows the agency's interactive map that allows a user to zoom to a variety of levels and obtain mapped information on bus stops, routes, light rail stations, transit centers, and park-and-ride lots located near a specified location. Interactive rail maps can be seen on the Web sites for LACMTA and the Washington Metropolitan Area Transit Authority (WMATA). In addition, the Dundee City (Scotland) Journey Planner works with a very easy and clear interactive map.[80]

Regional traveler information systems, particularly 511 telephone and web applications, are being implemented across the U.S. Many of the 511 systems are using voice recognition tools as part of the phone-based Interactive Voice Response (IVR) system. Transit applications are beginning to be incorporated into the 511 systems, which have typically started with traffic-related information. The multi modal trip planning tools also support Transportation Demand Management (TDM) efforts in a region. Parking and parking management applications will become another integral component of these systems.

The 511.org Web site that supports the San Francisco Bay area includes information on traffic conditions, transit (including access to the regional Trip Planner), ride share, bicycle, and other transportation-related information. Approximately 40 organizations have links to the Web site and approximately 24 transit agencies are a part of the Trip Planner service.

[80] www.dundeetravelinfo.com.

Figure 18 NJ TRANSIT Station-to-Station Application

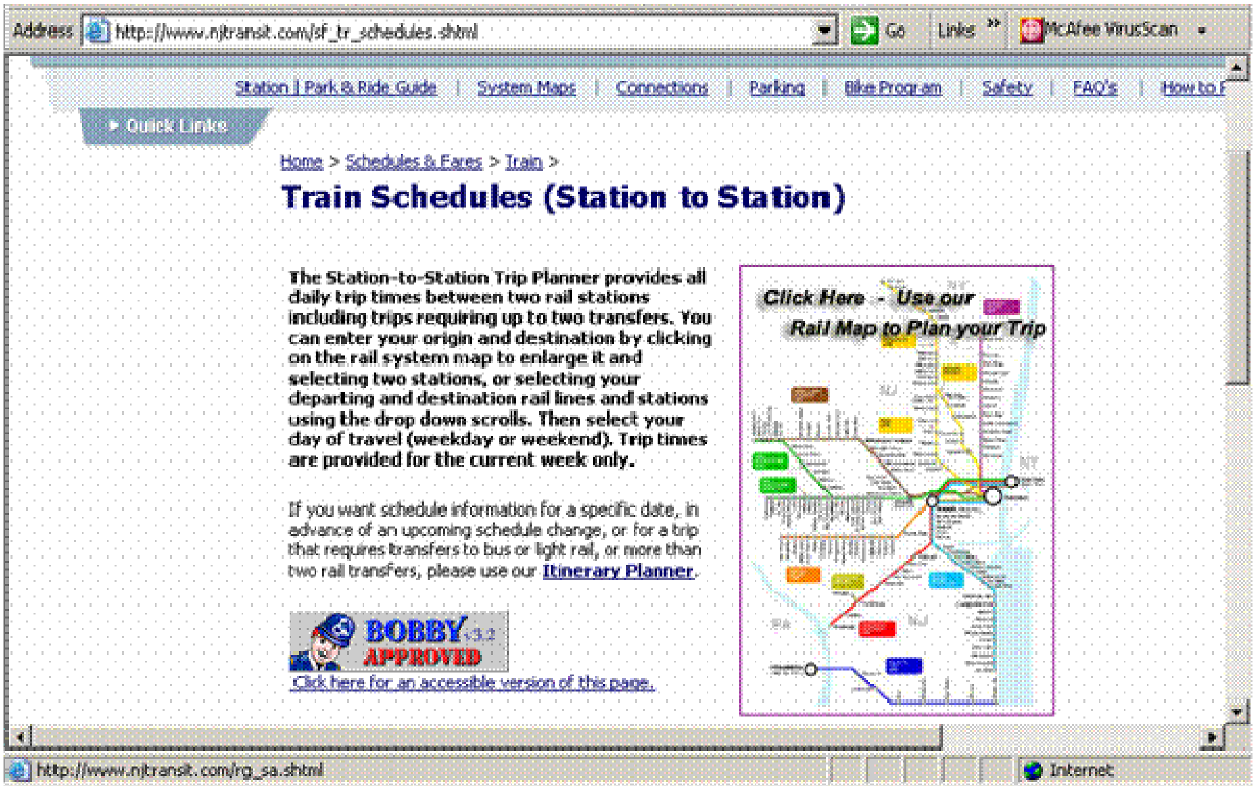


Figure 19 Wireless Options for Traveler Information at RTD-Denver

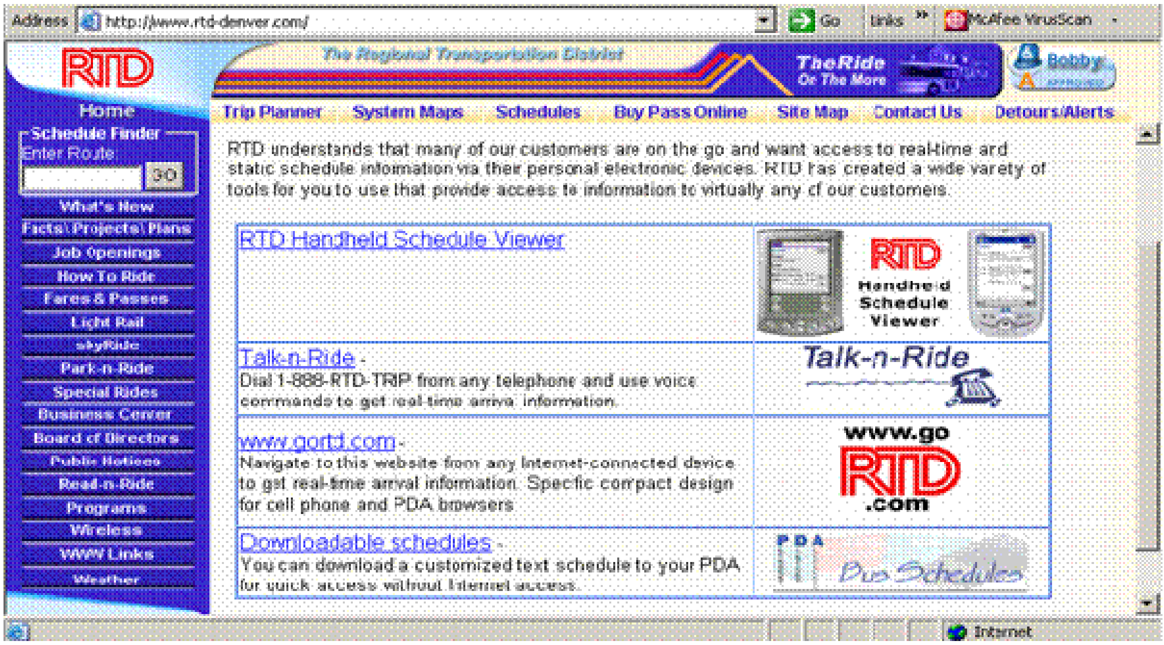
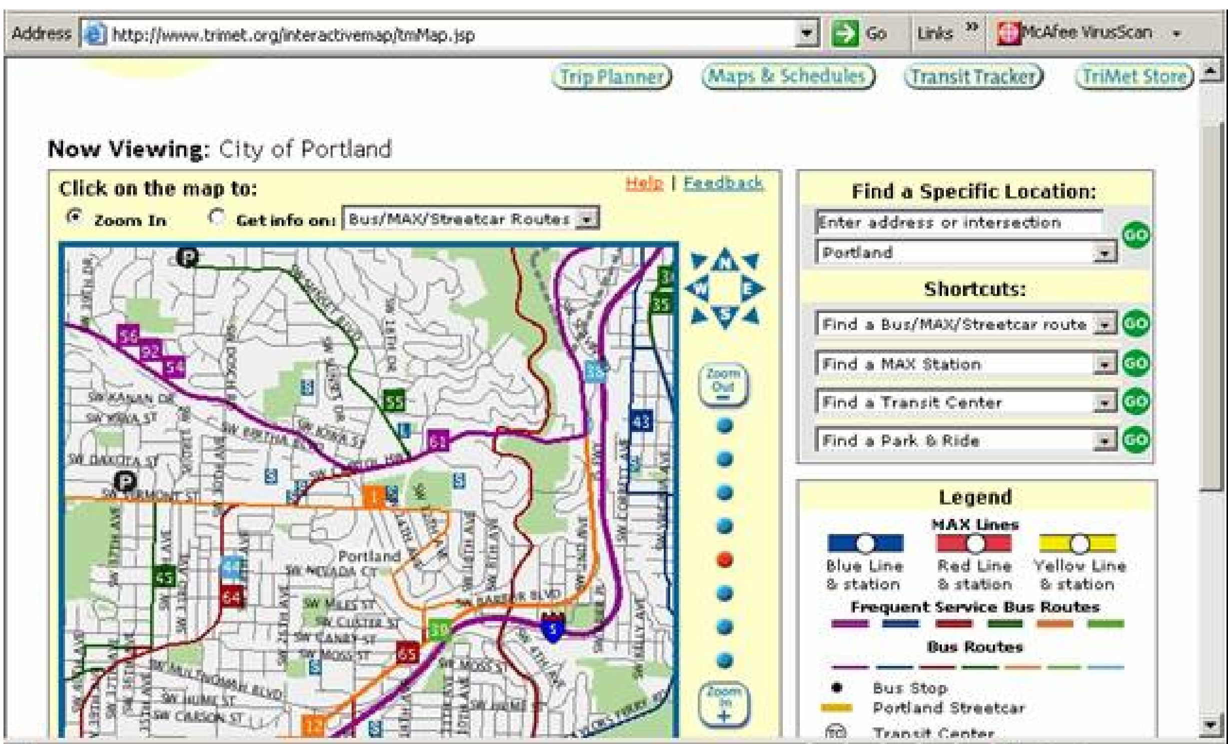


Figure 20 Example of TriMet's Interactive Mapping Options



5.3 Transit Trip Information Infrastructure

5.3.1 Technology Description

The transit trip information infrastructure is the "behind the scenes" blend of information technology tools and agency procedures that ensures the availability of data needed to provide transit trip information to the customer. The infrastructure described here supports both single-agency and regional approaches to ensuring an integrated set of data that supports scheduled and real-time trip information services, as well as different channels used to disseminate the information to travelers. The information infrastructure description was developed based on a combination of "best practices" information and lessons learned from the transit agencies interviewed. Communications technology infrastructure and issues, such as for wireless communication, are discussed in the Communications section of Chapter 2.

An effective trip information infrastructure is now of much more importance to transit agencies because of the large number of different, yet related, traveler information systems and channels that are being employed, as shown in Table 5-1. Transit agencies cannot afford to have redundant and inefficient data development and maintenance efforts for multiple systems.

Although most transit agencies distribute customer information via automated systems, data that feeds the systems are often developed and managed with manual, resource-intensive processes that require a significant investment of ongoing staff time to provide up-to-date information on a daily basis. These resources are even more pronounced when service changes are made and various regions are involved. If the data provided by traveler information systems are not accurate, the systems can either fail or not be fully used.

Newer IT technologies such as Web services and the development of a back-office data infrastructure can both help reduce the additional staffing requirements. Although few agencies have taken full advantage of the technology options available, there are some key examples of next-generation infrastructure tools and systems that clearly show the benefits of deploying a state-of-the-art transit traveler information infrastructure. Some of these examples are described below in Section 5.3.2, State of the Art.

A robust, state-of-the-art transit trip information infrastructure will support the incremental rollout of multiple traveler information services provided to multiple user communities, such as accessible information or information in other languages. The distinguishing features of a traveler information system infrastructure can be classified into three categories:

Technological Features
Data Integration Issues
Regional Considerations

5.3.1.1 Technological Features

The technological features that enable the enhancement and more creative uses of transit data consist of:

- Data-driven applications: Use of data management tools and techniques such as data models and sophisticated database design offer advantages over legacy application programming techniques that, even when using database technology, result in "stovepiped" applications and highly customized, difficult to maintain environments. A good example of a data-driven deployment is found at Metropolitan Transportation Commission (MTC) based in the San Francisco Bay area. MTC's Regional Transit Database is referenced geographically and includes a data engine that can integrate spatially related data "on the fly."
- A "three-tier" or "N-Tier" computing architecture: Use of a three-tier computing architecture (e.g., one tier would be the databases, another tier might be the business rules and applications, and a third tier might be the distribution channels for the information such as the Web) allows the separation between databases, business processes, and presentation to enable modularity, flexibility, and easier system changes.
- The use of open systems and standards: "Scalable" hardware and software approaches that enable the use of information technology (IT) and Web-based standards, commercial off the shelf software (COTS), and other technology systems are especially important "…to enable properly engineered components to be utilized across a wide range of systems with minimal changes, to interoperate with other components on local and remote systems, and to interact with users in a style that facilitates portability."[81]

5.3.1.2 Data Integration

The successful integration of transit data is also a key factor in supporting Traveler Information systems. There is a wide range of ways to integrate data to provide this support. For example, the integration of data needs to occur between a variety of data sets, a mechanism needs to exist to ensure that bus stops are accurately sequenced and integrated into the appropriate route patterns, and schedule and route data to support interim changes must be included as part of the data resources. Additional information pertaining to integration benefits, techniques, and issues is provided in Chapter 2, Integration.

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[81] See: www.sei.cmu.edu/opensystems/faq.html. This Web site provides a comprehensive description of open systems, standards, and interoperability issues.

5.3.1.3 Regional Deployment Considerations

Regional traveler information systems have extra, and somewhat more complex, components to their information infrastructures. They have extra issues with respect to the integration and quality checking of multi-agency data sources, more complex coordination and administrative procedures, and, if they are providing real-time data, they potentially have to manage differences in the quality of the real-time data.

5.3.1.3.1 Coordination and Administration Processes

A clear theme that emerged from the literature search and the interviews is that successful regional traveler information systems need a significant level of coordination in place between the partners and a number of administrative processes to be successful. For example, one element of a successful regional transit traveler information system is the effective handling of the schedules from the different transit partners. Agencies within a region may not change their schedules on the same date, and they may not have the same number of schedule changes in a year. In some cases, the new schedule version may apply to only a portion of an operator's schedule (e.g., one division or base such as a vehicle garage) rather than across the entire organization. As a result, clearly understood standards and procedures are needed to ensure that adequate configuration control and documentation of schedule data from the different agencies is achieved.

The solution for resolving this issue depends on the complexity of the differences between the partner agencies. For example, the Puget Sound Area updates their trip planner system every two weeks to manage the major and interim changes to the regional system. The San Francisco Bay Area's MTC "TakeTransit Trip Planner" manages the major schedule changes two weeks prior to the schedule change for each agency.

5.3.1.3.2 Real-Time Data Quality Management

A number of regional organizations are developing plans for presenting multi-agency and real-time information to their customers. A key challenge for these regional organizations is determining how best to present the data to the public in a reasonably consistent manner when the information accuracy varies between each transit agency. For example, the transit agencies may have GPS and AVL systems from different vendors and technology eras. The systems may also provide data at different frequencies (e.g., anywhere from one to five minutes), different levels of accuracy (e.g., 0.5 to 250 feet), or from different algorithms that provide the estimated time of arrival differently (e.g., is the arrival time estimated for a bus stop, or is it calculated as a schedule deviation from last time point).

5.3.2 State of the Art

A number of transit agencies have developed Traveler Information system data infrastructures that operate in an integrated manner, both internally and regionally. The benefits that arise from these state-of-the-art Traveler Information infrastructures include:

- The ability to have a more flexible, modular, and scalable system;
- The ability to be expanded to include other data sets and other presentation methods or channels over time; and
- A more cost-effective approach to data development and maintenance.

The following are examples of transportation agencies that have developed data infrastructures that support regional Traveler Information.

The RTA in Chicago provides regional oversight for three transit providers: Chicago Transit Authority (CTA), Pace Suburban Bus, and Metra. As a regional organization the RTA coordinates and integrates its Traveler Information projects with respect to the regional setting, the different transportation agencies, and the variety of transportation modes in the region. RTA is also helping to create the Illinois Transit Hub, which is a central repository for CTA, Pace, Metra, and other agencies. It collects data and establishes data interfaces and regional procedures. With centralized data, it can provide or display information to a range of agencies and customers, and through a variety of channels. RTA is also in the process of building a system to provide real-time vehicle location information to the public. Once data become available, they will be provided first to its Call Center and then to information signs.

King County Metro has made substantial investments in the design and development of its data infrastructure. Core data are defined by the agency, and they have a central source for those data. Each application may access the core data and transform that data as needed. The data maintenance procedures and accuracy standards are defined, and relationships among data elements are resolved in data committee meetings. The Customer Services group plays a key role in ensuring data quality for the Traveler Information systems by performing data updates and checking for errors in the data sets. Spatial data are available both to the GIS and the relational database system, allowing for easier links between spatial data and tabular data. A range of tools and utilities have been developed for facilitating data maintenance, locating bus stops on a map, identifying bus stop sequences, and conducting ad hoc data queries.

Portland TriMet has also invested in a well-planned transit and spatial data infrastructure that allows the agency to provide their staff and customers with a wide range of flexible Traveler Information tools. One of the areas in which TriMet excels is the spatial display of transit routes, facilities, and other information for the traveler. Their ability to do this is facilitated by their development and use of a location referencing authority table (Location Table). The Location Table serves as the "authority" for location references for transit point features. For example, a bus stop identified in the table with a unique ID number would be associated with several location reference methods such as the latitude and longitude, offset from the "at" and "cross" streets, and/or address. There are several benefits to having a Location Table as part of the Traveler Information data infrastructure, as described in the agency's "Location Referencing Guidebook." [82]

The MTC in the San Francisco Bay Area has developed, maintained, and operated a complex data infrastructure to support its 511 and regional Trip Planning systems. This infrastructure includes a Regional Transit Information System (RTIS) that serves as a centralized source of data and services that can be accessed over a wide area network (WAN) by a variety of agencies and users. It supports multiple applications developed by the regional transportation partners.

Some of the goals of the RTIS include:

- Avoiding data duplication;
- Optimizing data maintenance;
- Minimizing expenses;
- Upgrading the quality of the data;
- Sharing valuable resources;
- Supporting multiple applications with the same data set; and
- Improving access to the data.

Critical to meeting these goals is the use of standards, an open architecture, a well-developed data structure, institutional commitments, and documented agreements on how to support the system.

The major components of the RTIS include:

- A relational database;

[82] Data maintenance is greatly simplified when the location reference methods of multiple features only have to be updated in a single table. Another key advantage is the ability to remove the spatial requirement from other independent applications while linking them back to a robust and comprehensive spatial description. Applications that are largely tabular in nature do not need to have the added requirement of spatial tools and their associated licensing fees, yet can still be tied back to the spatial world through a simple location ID reference.

An open data structure;
A central spatially-enabled database;
GIS functionality;
A communication network;
Open access to MTC's transportation partners; and
Analysis tools.

5.4 Emerging Trends

A number of technology advances have occurred with respect to wireless communications, Web tools, geographic information and mapping tools, and data management that will drive the potential for some significant advances in Traveler Information services and the ease of providing them.

In particular, advances in mobile WiMAX and Dedicated Short-Range Communication (DSRC) technologies (see Communications section of Chapter 2) will provide more options for communicating information to and from a moving vehicle, helping to communicate arrival and departure times as well as other information. Communication to bus stops can occur with a wireless network and the use of Internet Protocol (IP) addresses.

In the very near future, technology enhancements will provide faster answers and more functionality, including interactive mapping that is quick and intuitive to use. However, it is not known when transit agencies and current transit trip planning vendors will be able to take advantage of these new trends.

Public data information repository tools will provide private Web promoters (e.g., GoogleMaps, MapQuest, HopStop, BusMonster, etc.) the ability to offer attractive, user-friendly traveler information and multimodal trip planning Web services. These services may be available via Web, voice over Internet protocol (VoIP), and mobile devices (e.g., cell phones, PDAs, etc.). They may integrate several data sources such as transit service, bicycle paths, traffic congestion, and incident information to provide users with several transportation alternatives and linked trips. In all likelihood these Information Service Providers will offer links or interfaces such as Application Programming Interfaces that transit agencies could use to customize these functions into their own Web sites. However, the applications may not initially support the following:

Fare data;
Trip selection based on minimization of cost;
Call center support capability (customer care, customer complaints and commendations);
Full array of IVR services;

- Free unlimited access (transit agencies my be charged use fees if they run over a certain number of transactions); and
- Turn-key installations located on an agency-owned or operated Web site.

5.4.1 Examples of Emerging Trends

Examples of emerging technologies that have resulted in state-of-the-art Traveler Information projects that are planned or currently under development include:

- New multimodal 511 systems with transit components (Voice Over Internet Protocol (VoIP) is under consideration for some of the projects);
- The use of wireless technology on buses so customers and operators can receive information;
- The use of wireless technology and IP addresses to support the communication of traveler information from the vehicle to wayside signs;
- New mapping and imaging tools;
- More complicated uses of voice recognition software; and
- Automatic integration of itinerary planning and real-time bus and rail status to provide personalized travel information tailored to each individual traveler's circumstances.

Below are specific examples of emerging trends in state-of-the-art Traveler Information applications.

- King County Metro is in the process of outfitting 30 buses with equipment to provide WiFi access on the bus for passengers. In this initial demonstration project to provide Internet access to passengers while in transit, commercial cell phone carrier infrastructure will be used to communicate the data from the bus WiFi hot spot (i.e., wireless access point for connecting to the Internet).

- The RTA in Chicago was recently awarded a $1 million grant from FTA to develop a Multimodal Trip Planning System (MMTPS), which will provide point-to-point directions for transit trips, driving trips, and other transportation modes. The goal is to provide users with a real-time, decision support tool to offer them the best travel options, considering mode, efficiency, cost, and convenience. The MMTPS will be developed using Transit Communications Interface Profiles (TCIP) and Advanced Transportation Information Systems (ATIS) standards in Extensible Markup Language (XML) to integrate existing single-mode trip planning and traveler information systems.

  Decisions will likely take into consideration:

  - Real-time incident data;
  - Highway congestion (travel times) data;
  - Integration of the existing transit system and highway data; and

Illinois DOT (IDOT) and local DOT highway/arterial monitoring system data.

The project is proceeding under a three-phased approach. Phase 1 will develop the core system, which will provide itineraries for a trip made by transit, driving, and a combination of the two. It will include real-time highway information. Phase 2 will add functionality to the core system and will include real-time arterial data, real-time transit data, parking information, bicycling information, emissions avoided calculations, and paratransit dispatching. In the third phase, the system will incorporate other intercity operators and broader participation (e.g., Amtrak, Greyhound, and Gary-Milwaukee).

RTA is also planning to provide real-time transit information from the three transit agencies it oversees (CTA, Pace, and Metra). The system will incorporate real-time data from the automatic vehicle location (AVL) systems of all three agencies. Planned schedule data will be collected into three separate databases using the native formats provided by each operating agency. RTA staff will work with the respective agencies to verify and validate the datasets. After the data are validated, they will be normalized, projected to bus stop or station level schedules, and stored in a central database. Real-time data feeds will come directly from each agency's communications center to the RTA server where they will be extracted, transformed, loaded, and made ready for distribution.

Capital Metro, Austin, TX, is in the process of implementing IVR access to their Trip Planner system using voice recognition software. The agency is working to make the implementation more robust, which includes dealing with the multiple languages and accents that are common in the Austin area.

Two advanced parking management and information systems are currently being implemented, one in Montgomery County, MD, and the second by Metra in the Chicago area. The Montgomery County system will inform motorists via portable Dynamic Message Signs (DMS) when the parking station is full, and suggest that they park at an alternate satellite parking lot or at another station parking facility.

The Metra Parking Management Guidance System is a two-year demonstration project that includes eight DMSs located in a corridor with two commuter rail stations. Loop detectors in the pavement at the rail station parking areas will detect cars entering and leaving the lot. Information from the loop detectors will be sent to a software system that will estimate the available parking (taking into consideration passenger drop-off activity and other factors necessary for estimating fill rate) and determine the message to be sent via wireless communications to the DMSs. The DMSs will provide motorists with a real-time estimate of the number of available parking spaces at the respective stations. If parking at a station is unavailable the sign will indicate that the lot is full and suggest an alternative parking option. Additional information on parking management is provided in Chapter 7, Transportation Demand Management.

TriMet is currently in discussions with GoogleMaps to explore options for providing easier to access, more attractive traveler information, and possibly more mapping views to its customers. The agency is also in the process of implementing a Dynamic Timetable Generator (DTG) to more quickly and efficiently update their schedule data on their Web site. A prototype of the DTG was originally developed as a part of the TRB Transit IDEA Project 39. The DTG prototype application was built using multiple standards (e.g., TCIP, XSLT) and open source software (Apache Web Server, MySQL, Linux, and Tomcat) to ensure that the system was an "open" one. The prototype was built using a database-driven approach to derive the information from the native authority, and a 3-tier computing architecture to enable migration to different agency native formats and timetable presentation formats (e.g., color schemes, ADA formats, etc.).

On Cape Cod in Massachusetts, a prototype demonstration of an *e-transit village* is ongoing, which includes using buses as "WiFi hotspots" and implementing state-of-the-art transit ITS applications. The project is currently being conducted by the GeoGraphics Laboratory at Bridgewater State College using the campus transit system provided by the Brockton (MA) Area Transit Authority. One of the project's goals is to use affordable, off-the-shelf products, standards, and open-source software wherever possible.

The proof-of-concept project uses a wireless local area network infrastructure (WLAN) on campus and international standards (WiFi or wireless fidelity 802.11b). Transit buses are equipped with custom-built mobile data computers that contain global positioning system (GPS) receivers, which communicate with the campus outdoor WiFi network through a high-powered wireless card and an external wireless antenna. All hardware is COTS, while the software is freeware (e.g., Linux) or resides in the public domain.

The mobile data computers also have an emergency alarm and an Internet video camera. The Internet camera can be controlled remotely by the operations center to pan, tilt, and zoom. Custom-built software stamps the image file from the Internet camera with GPS date/time and precise latitude and longitude information, and then transmits the image at one-second intervals to the GeoGraphics laboratory's Web server and database using Internet protocols. As a result, the following transit ITS applications can be provided:

Each bus can act as a mobile Internet access point (AP) for WiFi-capable laptops and PDAs used by campus community bus patrons;

The system provides AVL Web-mapping with one-second refresh rates. It also provides the estimated time of arrival of each vehicle at principal bus stops. Transit vehicle location can be accessed by customers in the community at their desktop or on campus kiosks, from their wireless laptop/PDA at bus stops, or while onboard the bus; and

To provide better emergency response, real-time onboard video is transmitted at one-second refresh rates to the Operations Center, Police Department Dispatcher, and to first responder vehicles when a MAYDAY alarm is signaled. During all other times, video is transmitted in real time over the Internet and to video archives posted at the GeoGraphics Lab Internet site. A transit consumer can use these services to see video from the approaching vehicle and potentially recognize where the bus is on its route.

The demonstration project has succeeded at most of its goals. The project team is now working on resolving those issues that afflict most mobile wireless demonstrations, that is, how to maintain a connection when moving between WiFi locations. AVL data are transmitted every second without difficulty, but the transmission of large blocks of video data in real-time sometimes results in dropped signals. The project is also exploring how to extend the range of the wireless capabilities to more rural areas.

5.5 Challenges and Lessons Learned

Developing accurate, timely, and complete data for the traveler information systems is one of the biggest challenges to implementing advanced traveler information systems. If the data are not correct, the systems will not operate efficiently or effectively. When the information provided to travelers is not dependable, the systems will not be fully used. Customers will stop using a system or the transit agency will terminate the service because of the ill will generated with customers when incorrect information is provided. Similarly, transit agency customer information staff will not use trip planning systems when the data in the system is old or incorrect, preferring instead to rely on their internal knowledge, manual references, or other data sources.

5.5.1 Key Lessons Learned

The most important lessons learned by those transit agencies interviewed are to:

Allow adequate time to develop the necessary data, and ensure that they will be correct and available when the system is to be implemented; and

Ensure that processes and resources are in place to address ongoing data maintenance.

5.5.2 Regional Trip Planning Lessons Learned

When implementing Regional Trip Planning systems, not all transit agency partners have equal financial and staffing resources. The regional projects have significantly more difficulty when different GIS and scheduling systems provide the data. There is an additional challenge of coordinating all the stakeholders, both internally and externally. For the project to be successful:

Each partner agency must have the necessary data and communications infrastructure in place;

Common standards should be established and adopted;

Additional resources are needed to resolve how to handle shared data features and integrate the various agency data sets. For example, the regional trip planning applications require interagency transfer locations, a common base transportation network, and regional consistency in naming and locating services, landmarks, street names, and other elements;

Operational rules and business processes need to be coordinated or defined further to make ITS systems work;

Agencies must be allowed to implement their portion of the regional system at different times, given their different capabilities and resources;

Agencies need to cooperate, be flexible, and assist each other;

Memoranda of Understanding that address operating and system administration procedures, as well as other issues, should be executed and regularly updated among regional trip planning partners; and

Internet and other automated tools are needed for the regional partners to upload and maintain the data they provide, such as schedules and service bulletins. The tools can lessen the level of effort needed to participate in a regional project and help ensure continued participation.

5.5.3 Maps and Networks Lessons Learned

The features and accuracy of the base map, including the street and transportation network, are also critical to the success of many traveler information systems. Having only one source map for the various information systems saves development and maintenance resources and improves accuracy.[83]

5.5.4 Voice Recognition Lessons learned

Although the voice recognition components of interactive voice response systems have improved over time, transit agencies have discovered that there are still significant problems that must be overcome before implementations can be successful.[84] Issues that have caused problems for voice recognition software include the clarity of signals to and from cell phones, background noise, speech accents, soft-spoken customers, volume capabilities of the phone system, and the complexity of the task and voice options. IVR with voice recognition in support of trip planning systems that allow for a large set of complicated street names can pose data development and performance challenges. Some agencies suggested that the voice recognition component be implemented last, after most of the other systems and data issues have been resolved.

5.5.5 Real-Time Lag Lessons Learned

The communication of the real-time position of the bus generally has a lag that can pose problems for real-time next bus information systems. A number of elements, such as those listed below, can affect the lag time:

- Polling rates for AVL systems;
- The capacity of the data radio channel for transmitting data; and
- The design of the system (i.e., what data are transmitted via what path between the vehicle, the center, and the distribution channel).

These elements and others can limit the timeliness and the accuracy of estimated real-time bus arrival and departure times. The communications lag is particularly frustrating for a passenger and customer service if the lag results in a delayed report of a bus that has already departed a stop.

In the future, an increasing number of transit agencies will be able to employ GPS-based AVL that includes variable position reporting rates. As vehicles' on-time status changes, especially as they approach a stop, as determined either onboard or at the fixed end, they report their position and speed more frequently. When on-time status is determined to be relatively constant, and when far from a stop, reports are less

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[83] FTA funded the development of a guidebook that identifies issues, benefits, and options pertaining to base maps and the spatial definition of transit features such as routes, stops, and timepoints. The guidebook is titled, "Defining Geographic Locations of Bus Stops, Routes and Other Map Data for ITS, GIS and Operational Efficiencies: Best Practices for Using Geographic Data in Transit: A Location Referencing Guidebook" (Transit Standards Consortium, October 2003, http://tsconsortium.org/LRG_FinalPublication.pdf).

[84] Staff at Capital Metro in Austin stated that knowing when and where customers "give up" and exit the system is helpful for designing improvements. Using markers at the exit points and tracking software can expedite troubleshooting.

frequent. This minimizes real-time lag at critical times while avoiding needless bandwidth utilization.

5.5.6 Communications Lessons Learned

The type of communications systems used cannot only affect data lag time issues, but can also impact the types and amount of data that can be transmitted, the cost of the implementation and maintenance of the communications infrastructure, and many other issues. This is especially true for systems that communicate real-time system performance. For additional information on the challenges and emerging technologies pertaining to communications, see the Communications section of Chapter 2. A long-range plan for communications technologies and ITS applications, particularly onboard the bus, is important for efficient transmission of data.

5.5.7 Bus Stop Data Lessons Learned

Accurate bus stop data is critical for traveler information systems, particularly next-bus and trip planning systems. In addition, a process (ideally automated) must be in place to create "bus stop sequence" data. The process must ensure that the proper sequencing of bus stops along a route is known, handling issues such as "skip stops," inactive stops, and stops on the far side of an intersection where a bus turns.[85]

5.5.8 Floodgate Messages Lessons Learned

For 511 systems, when there are major incidents or events, agencies have learned to use floodgate messages (one of the first messages that you cannot skip), which shortens call durations significantly. Since 511 systems typically experience high call volume at specific peak times, floodgate messages are one way to handle the peaks rather than overbuilding the system to cover them.[86]

5.5.9 Miscellaneous Lessons Learned

- Conduct limited field demonstrations first;
- Avoid the tendency to quickly buy systems. Instead, initiate all steps of a systems engineering approach. Do not skip steps such as the definition of key stakeholders, functional requirements definition, alternatives analysis, detailed requirements definition, development of a thorough testing and acceptance criteria plan, and development of an Operations and Maintenance Plan;
- Budget for the time and resources needed for systems engineering;

[85] The "Bus Stop Inventory Guidebook," (Transit Standards Consortium, August 2000. http://tsconsortium.org/BusStopInventoryBestPracticesandGuidlines.pdf) is an excellent resource that identifies a wide range of bus stop related issues and solutions.

[86] From discussion of the Arizona 511 Model Deployment on the Talking Operations forum on "Rural Issues: 511 and Traveler Information," on July 27, 2005, www.ntoctalks.com.

- Include all the key stakeholders early in the process. Many different parts of transit need to be involved in the projects, particularly in the data development and maintenance effort;
- Improve the customer's experience with the transit data, by having consistency between the names and abbreviations used on paper timetables, bus head signs, Web sites and other materials;
- Spend time getting the Internet interface right for the customers. Transit Web site guidelines are available from Volpe;
- Use standards where possible;
- Anticipate future needs when building system requirements and have a far-sighted project architecture that is open and capable of expansion;
- Trip planning systems need to be fine-tuned and users need tips on how to use them most effectively; and
- Have a mechanism for customer feedback.

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Chapter 6 Transit Safety and Security

6.1 Introduction and Technology Overview

6.1.1 Transit Safety and Security

For decades, public transit has used technology to improve both the safety and the security of its operations to prevent or mitigate intentional or unintentional incidents involving the well-being of transit employees, customers, and physical assets. From a *safety* perspective, technologies have long been used to help monitor the operating status of engines, drive trains, brakes, wheels, and tires. Video and other technologies used in and around transit facilities have helped to monitor weather and other environmental conditions for safe operations of rail and passenger terminal services.[87] Use of such technologies has certainly helped to reduce accidents and other *unintentional* causes of harm to employees, customers, and physical assets. From a *security* perspective, technologies such as radio communications systems, video surveillance systems, automated vehicle location (AVL) systems, and other advanced technologies, have helped agencies to monitor situations onboard vehicles and at transit facilities, thus improving prevention and response to *intentional* acts of crime or violence. As described below, the advent of greatly improved digital video and communications technologies has helped transit agencies to significantly enhance both safety and security by providing systems to guard against, and respond to, both unintentional and intentional harm.

Central to designing and deploying technological solutions for safety and security applications is transit's ability to employ or refine existing ITS and information technology (IT) systems. Forward-looking transit agencies are turning to existing IT technologies and standards (e.g., Internet Protocol or IP, Extensible Markup Language or XML), as well as off-the shelf-technologies to provide timely information to help protect and secure the communities they serve. Agencies using real-time information systems are assessing the possibility of applying Web-based services architectures to rapidly deploy information such as traffic routes and emergency bus schedules. Advanced sensors used in the military to detect hidden bombs are now being further refined so they can be used by transit and others to quickly and accurately scan people and luggage. Additionally, broadband networks tying together land-based and wireless technologies are being designed and installed around major cities. New data visualization tools that can handle spatial and graphic elements to analyze network traffic patterns may also be applied to future incident response systems that integrate

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[87] See: Transportation Research Board Research in Progress: *Safety and Security Technology Transfer Support*, http://rip.trb.org/browse/dproject.asp?n=9381, 2002-ongoing.

map data gathered from Global Positioning Systems (GPS). Applications of these new innovations in ITS and IT systems present the most exciting examples of the state of the art in transit safety and security.

6.1.2 Increased Sense of Urgency

After the terrorist attacks in New York City and Washington, DC on September 11, 2001, there has been an increased sense of urgency within the transit community to develop and deploy technologies to assist in counter intelligence, infrastructure protection, emergency response, and post-incidence recovery from intentional acts of violence against public transit employees, customers, and physical assets. Furthermore, the economic and social impacts of major domestic natural disasters such as severe hurricanes underscored the criticality of establishing policies, plans, and procedures for transit to operate in emergency response and recovery mode.[88]

In fact, since 9/11, data sharing has been a top priority at all levels of government, as well as between government and business. However, providing access to data from multiple systems has proven to be a technological challenge. Poor regional coordination, tough data management problems, and infrastructure limitations are complex issues that will take time to implement. The much publicized failed attempts at data sharing illustrated just how complex things can get when systems have to be woven together and coordinated with social and local community expectations.

Other challenges impeding the deployment of advanced technologies include insufficient funding, deficient maintenance, and politics. Because of these challenges, few, if any, transit agencies have demonstrated, tested, or deployed much-needed technological systems such as advanced bomb-detecting technologies or other passenger screening systems. The ability to accurately detect chemical or biological agents within transit facilities and vehicles is considered by experts to be many years away and requires the expenditure of hundreds of millions of dollars. In the interim, transit has increased security patrols, and instituted better coordination and cooperation with law enforcement, emergency medical teams, and fire departments.

Despite the slow progress, there have been some emerging cases where transit personnel have convinced their governing boards to make investments in advanced security technologies — and the necessary support systems, training, and maintenance programs — that will help make their agencies safer and more secure. Most of these state-of-the-art systems involve two technologies: digital video and broadband wireless Internet. Combined with rapidly increasing data storage capabilities, these technologies

[88] T. Littman's article, "Lessons From Katrina: What a Major Disaster Can Teach Transportation Planners," points out how failures in planning and the breakdown in communications among public agencies compounded the disaster in New Orleans in August-September 2005.

give transit safety and security personnel the ability to monitor high-resolution, real-time, digital video from both vehicles and fixed facilities such as passenger stations and maintenance yards. The ability to make a visual confirmation of situational conditions provides a significant improvement in the ability of safety and security personnel to accurately assess an incident and deploy appropriate prevention, mitigation and recovery responses. Furthermore, through cooperative agreements with law enforcement, fire, and emergency medical teams, transit personnel have demonstrated that it can expand its "view" of systemwide operations to provide even greater geographic coverage.[89]

How well transit responds to homeland security measures and federal/state/local disasters depends in large part on the amount of funding government and business are willing to commit to technologies that protect people and assets. In addition, for technologies to truly advance transit safety and security, hardware and data standards must be developed, tested, taught, and maintained. Finally, as with most applications of technology, it is not the technology itself that poses the biggest challenges; rather, the greatest challenges lie in the policies, procedures, processes, and attitudes of the people involved. Thus, as important as it is to be able to procure and deploy the hardware and software for state-of-the-art technologies, it is just as important to develop and maintain interdepartmental and external relationships that involve stakeholders from various transit departments and related outside organizations so that use of the technologies can be optimized across political and legal jurisdictional boundaries to truly serve regional areas and the nation as a whole.

6.2 Onboard Safety and Security

6.2.1 Technology Description

Central to most transit agencies' onboard safety and security systems are voice communications and video assessment technologies.

6.2.1.1 Voice Communications

Radio communication between operating vehicles and command centers has been a mainstay for public transit operations for decades.[90] Having voice contact enables vehicle operators to inform dispatchers of unusual delays or emergencies in real time.

[89] See Section 6.6.1, NJ Transit example of expanding its video assessment system to include external partners.

[90] See "Telecommunications Systems—Radio Systems" in TRB's Transit Cooperative Research Program (TCRP) Report 43: "Understanding and Applying Advanced On-Board Electronics, pp. 17-18.

However, the use of the technology is limited by frequency bandwidth restrictions and a lack of standardization across vendor products and jurisdictional boundaries.[91]

6.2.1.2 Video Assessment Systems

Commonly referred to as video "surveillance" systems, the most basic video assessment systems produce simple black-and-white images. These images are scanned every few seconds from stationary installations onboard buses or trains and then uploaded and archived when the vehicles return to the agency. The most advanced systems produce full-color digital video recordings that are transmitted in real time from pan-tilt-zoom installations on transit vehicles via wireless broadband local area networks (LANs) back to agency operations centers. These systems are the "eyes" of transit management and provide important real-time monitoring and archival documentation of onboard vehicle incidents.

6.2.2 State of the Art

6.2.2.1 Interoperable Radio Communications

There have been many regional, state, and federal efforts to achieve radio voice communications interoperability between and among agencies that operate large fleets of vehicles, such as police, fire, and emergency medical teams, and operating agencies such as public transit.[92] Yet, to date, there still are no national standards for radio interoperability. As a result, local first responders and public transit are often left to use proprietary, noncompatible electronic radios with nonstandardized data definitions and are unable to communicate across agency or organizational boundaries during a crisis. In addition, this lack of standardization results in inefficient redundancies and an inability to leverage large radio infrastructure investments such as transmission towers, electrical switches, and power generation equipment. As a result, the state of the art of today's "interoperable radio communications" cannot be considered "advanced."

There are, however, two exciting examples of emerging technology that warrant attention. The first example is a "transit mobile broadband communications" system that has been implemented in several metropolitan areas, including Cedar Rapids, IA. By using a system of wireless Internet access hubs and equipping transit vehicles with inexpensive wireless modem cards, such systems can provide seamless Internet access throughout a transit corridor. Thus, a virtually endless variety of data and information

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[91] An inventory of radio communications systems compiled by Orbital Systems is provided at www.tms-online.com/projects_transit_index.html. Lack of standardization is apparent in the survey results.

[92] See: Department of Homeland Security SAFECOM program information at: www.dhs.gov/dhspublic/interapp/editorial/editorial_0339.xml and a review of the program's status by the Government Accountability Office at www.gao.gov/new.items/d04494.pdf; State of Texas, Radio Communications Interoperability Plan at www.atcog.org/Tx%20Radio%20Communications%20Interoperability%20Plan.doc.

packages can be communicated to and from vehicles within the corridor. Deployment of such "broadband communications corridors" may finally provide an interoperable platform for voice and data communications previously not achievable by traditional radio systems.

The second example is the Capital Wireless Integrated Network (CapWIN) program, a partnership between the states of Maryland and Virginia and the District of Columbia to develop an interoperable first responder data communication and information sharing network.[93] The project seeks to enable data interoperability for first responders wherever they are. To achieve this vision, the CapWIN program has developed a unique data sharing system and set of applications through the participation of multiple state, local, and federal partners. The CapWIN system is currently available free of charge to first responders across Maryland, Virginia, and the District of Columbia, as well as federal agencies. While these systems do not focus on transit, the methods and results of CapWIN efforts are very similar to what would be needed in a transit context.

6.2.2.2 Video Assessment Systems

While many transit systems use low-resolution black-and-white scanned image technology, there are virtually no current installations of sophisticated, digital, color video assessment systems onboard buses or trains. The primary obstacle has been the lack of bandwidth to transmit high-density digital video from moving vehicles.[94] As improvements in bandwidth technology are made, such applications are certain to be a high priority for transit agencies.

6.3 Station/Facility Safety and Security

6.3.1 Technology Description

Video assessment systems are the linchpin in most transit agencies' station and facility safety and security systems because they have the potential to tie together many other stand-alone aspects of safety and security systems, such as fencing, barrier, lighting, access control, sensor, control, and crisis management systems. For example, an accidental fuel spill at a maintenance facility can be seen and monitored on real-time video, providing transit safety personnel the ability to quickly assess the appropriate type and level of emergency and cleanup response. A security example would be software used with a video monitor at the entrance of a rail tunnel that would trigger an

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[93] See general descriptions of CapWIN at: www.capwin.org/.

[94] Again, the potential gains from the innovative, mobile broadband communications system in this case would be significant. For recent and latest updates on this rapidly evolving technology, see http://zdnet.search.com/search?q=mobile+broadband, www.spectrum.ieee.org/WEBONLY/resource/jun05/0605ntv.html, and www.spectrum.ieee.org/WEBONLY/resource/sep05/0905nkor.html.

automated alarm that would alert security personnel to a vehicle or persons engaged in unauthorized activity. Transit management can achieve significant returns on most of its safety and security investments by designing, deploying, testing, and training in the use and maintenance of a video assessment system that leverages an agency's other safety and security assets.

The primary advantage to video assessment systems is their ability to record and archive information for real-time and archival use. For example, video makes it possible to determine whether one or more persons "piggybacked" off a single access card entry into a control room, whether it was a human intruder or an animal breaching a fence at a maintenance facility, or whether there are casualties resulting from a chemical release on a station platform. Acting in stand-alone mode, access control systems, fence alarms, and chemical detection sensors can only provide minimal prevention and detection. Combining these systems with video, however, significantly enhances their effectiveness.

Likewise, the importance of a robust communications network that can enable broadband access to the Internet cannot be overemphasized. In addition to ensuring sufficient bandwidth to transmit high-resolution digital video, the network must also ensure that network load balancing can be achieved efficiently. There are new tools available to effectively monitor network loads,[95] and attention should be given to this critical aspect of network-based technologies to ensure optimum performance of all technology components.

6.3.2 State of the Art

Current state-of-the-art intelligent video systems are those that make digital video accessible from any PC or personal digital assistant (PDA) using Internet access protocols. Access is gained by secure login made through an established virtual private network (VPN) to ensure the best network security available, while leveraging the broad coverage of the Internet. Typically, no special hardware or software is required to view and control the video network. Access to the system can be obtained with a standard PC, an Internet Web browser, a virtual private network (VPN) account to log in, and an authorized user name and password. Digital video assessment systems that are Internet-based are easy to expand, and performance quality and reliability will continue to improve as broadband availability improves and data storage costs continue to decline in the future. Once digital video is captured, software applications can identify intruders, unattended baggage, unusual crowd formations, etc. Software

[95] Portland Tri-Met has been aggressive in planning for and accommodating the deployment of ITS technology on its information technology infrastructure. See article at: www.netscout.com/docs/reprints/NetScout_reprint_IWA_Turning_Transport_On.pdf.

can also provide a means of integrating information from chemical and biometric analytical tools.

What makes any video assessment system effective is a combination of well-specified, deployed, and maintained technology, along with a body of knowledgeable and engaged users. For example, the New Jersey Transit (NJT) video assessment system is certainly technologically "state-of-the-art," but what makes it truly effective is the interdisciplinary, multi-agency, multijursidictional way in which it is used. The functional requirements for the system were defined under the direction of the NJT police chief, who worked closely with the head of the Information Technology Department who, in turn, specified the technical aspects of the system. The police chief culled requirements not only from transit operations, but from strong working relationships with the New Jersey State Police, Amtrak, New York City Metropolitan Transportation Authority, and the Port Authority of New York and New Jersey.

Now that the NJT video assessment system has been deployed, a suite of software provides live and archived feeds that count customers, detect dropped bags, and track intruders in secure areas such as tunnels and bridges. The system also monitors no-parking areas and detects unusually large crowds that might indicate some kind of problem. Live and archived feeds are shared appropriately by NJT with all the other cooperating agencies (as well as fire, law enforcement, and emergency medical teams) to enhance multi-agency intelligence sharing and responsiveness to incidents throughout the region's bus and rail networks.

Benefits to the agency beyond safety and security are significant. When people know that incidents have been recorded, they are less inclined to file a false claim against the agency, resulting in substantial savings not only in claims losses and trial and litigation time and expense, but in case processing and investigations as well. Customer service complaints are also checked against video records to verify the accuracy of the complaints. Additionally, maintenance can view video from a PC, mobile phone, or PDA to determine how to prioritize sending crews out to clear snow or debris.

6.4 Incident Response

6.4.1 Technology Description

Incident response[96] can be segmented into three broad categories: detection/ assessment, response/evacuation, and communications. Technologies that support these functions are described below.

6.4.1.1 Detection/Assessment

There have been a few isolated attempts to develop applications that detect chemical release at transit stations, including a significant effort sponsored by the U.S. Department of Homeland Security called PROTECT (see below). Another is a "puff portal" where air is circulated around a passenger for 15 seconds and analyzed for explosive particles. This latter technology is being tested at airports and may have application at major rail stations in the future. Onboard panic alarms, radio, and video systems also help with detection.

6.4.1.2 Response/Evacuation

Computer Aided Dispatch (CAD) is a valuable tool in incident response, particularly when supported by an effective Geographic Information Systems (GIS).

For onboard and transit station facilities evacuations, electronic signage and public address systems can help inform and instruct transit passengers on safe egress from harm.

For area-wide evacuations, the primary focus of transit technology efforts for public information and emergency evacuation has been related to the nation's 511 Travel Information System.[97] The Federal Communications Commission (FCC) designated 511 as the national travel information number in July 2000. The first 511 service was launched less than a year later in northern Kentucky. By early 2005, twenty-five 511 systems had been launched with several more nearing deployment.

Many transit agencies participate in regional 511 planning and deployment efforts. The degree of success is contingent upon the agencies' ability to collect and organize their

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[96] Shortly after 9/11, transit agencies gathered in a series of "Connecting Communities" workshops sponsored by the Federal Transit Administration (http://transit-safety.volpe.dot.gov/training/Archived/EPSSeminarReg/default.asp) and determined that transit response to the then-Office of Homeland Security's Threat Level Response Recommendation should include two additional categories above "Code Red": Black would indicate "Under Attack" and Purple would indicate "Recovery." Incident response would therefore be considered the activities related to Code Black. See: http://transit-safety.volpe.dot.gov/security/SecurityInitiatives/ThreatLevel/default.asp.

[97] http://www.deploy511.org/.

data and information efficiently and effectively so that they can be shared with regional partners. While the 511 systems are developed for general information about travel services, having them in place with transit participation effectively provides a communications platform upon which transit can communicate with partner agencies and the general public under emergency conditions as well. The Bay Area's 511 transit information Web site is one of the best examples of a functioning technology that can be used as a "platform" upon which an effective incident response strategy can be built.[98]

6.4.1.3 Communications

All transit agencies have radio systems to maintain communications between agency dispatch centers and fleet and supervisory vehicles. Many systems are stand-alone and do not allow for communications with law enforcement, fire, or emergency medical teams from neighboring or contiguous jurisdictions. In some instances, radio interoperability with other agencies has been achieved where transit agencies operate as part of a county administration.[99] The lack of national radio interoperability has resulted in a tenuous reliance on cell phone-based communications, despite issues of lost signals between transmission zones and switch capacity constraints during periods of high volume calling.

6.4.2 State of the Art

6.4.2.1 Detection

Significant research and development progress has been made by the Program for Response Options and Technology Enhancements for Chemical/Biological Terrorism (PROTECT). PROTECT is an operational chemical agent detection and response system intended to significantly decrease response time, which, in the event of a chemical attack, will save human lives. The system includes detectors that sense chemical agents, video for incident verification, a computer program to model the spread of contamination in the subway, above-ground flow modeling for dispersion of toxic materials from street vents and station exits, and wireless communication for emergency responders.

PROTECT has been installed, tested, and placed in service in more than five Washington Metropolitan Area Transit Authority (WMATA) subway stations since 2003, and is being expanded. It is also currently undergoing tests in Grand Central Station in New York City, at South Street Station in Boston, MA, and in Baltimore, MD. Plans are also underway to begin specifying a system for the Regional Transit Authority (RTA) in Chicago. Although the system is limited to detecting chemicals, research and

[98] http://www.transitinfo.org/index.asp.
[99] Seattle King County Metro and Miami-Dade Transit are two examples.

development efforts are underway to integrate radioactivity sensors to enable detection of "dirty bombs" in transit facilities.

The PROTECT effort has included robust testing under live conditions at transit stations, and lessons learned have been well documented and applied to subsequent test sites. Results to date indicate promise in achieving the goals of the program, and applications at additional major transportation terminals and stations are anticipated. Unfortunately, the high cost of such systems, especially the integrated testing and calibration of the hardware, software and procedural components will place the technology out of the reach of most transit systems in the near future. However, as more agencies procure the technology in the future and the systems are upgraded, it is hoped that the costs and risks associated with system deployment will decline.

6.4.2.2 Response/Evacuation

Technology currently plays only a minor role in the evacuation of population groups subject to the effects of a major incident. Technology use will increase as more people adopt the use of computers and handheld devices, and as more transit agencies develop robust, real-time information systems that can collect, assess, and transmit relevant emergency evacuation information via information service providers to remote kiosks and other transportation and emergency management control centers.

6.4.2.3 Communications

As demonstrated not only by the 9/11 communications failures at the World Trade Center (in which hundreds of firefighters were sent up into the towers, even as evidence of the imminent collapse of the towers was becoming known) but by the Hurricane Katrina and Hurricane Rita evacuations as well, the most significant role technology can play in incident response is to provide timely and reliable communications for emergency responders, including transit. Given the lack of interoperability standards in radio communications systems among transit, law enforcement, fire, and medical response teams, the current state of the art in transit incident response communications is a tenuous reliance on ordinary cell phone technology.

6.5 Incident and Disaster Planning Support Systems

6.5.1 Technology Description

The basic concept of incident and disaster support systems is a simple one: provide a way for transit managers to access critical information concerning their agency's assets, policies and procedures, regional contacts, alternative scenario plans, and so on. In addition, safety and security incident tracking and analysis can help planning and resource allocation decision making.

Several transit agencies have used, or are considering using, software packages that provide an automated platform for managing crises. These incident and disaster support systems provide a way to collect and organize data (e.g., resource lists, deployment updates, SOP checklists), maps, photo and video images, and crisis management plans. These support systems, which essentially are platforms for managing large quantities of multimedia data and information, provide transit agencies with a tool that can make critical incident and disaster response management more efficient and effective.

There are dozens of software providers[100] with products ranging in scope and depth from basic database management of incident tracking, emergency contact lists, and asset management, to more sophisticated, customized features such as:

- Quick situation reports;
- Real-time weather tracking sources;
- Standard Operating Procedures (SOPs) integrated with emergency plans;
- Geographic Information Systems (GIS) map locations of incidents;
- Dashboard indicators of the real-time response capabilities of the organization in both tabular and graphical formats;
- Integrated chemical management that maps chemicals by location and links them to material data sheets; and
- Risk analysis tools for nuclear, biological, and chemical warfare and accidental industrial or transportation chemical releases.

6.5.2 State of the Art

There are many transit agencies and other governmental organizations that are using or have tried some form of incident and disaster support software. The benefits can be significant for the individual agencies, to the extent that there is useful data and information to load into the software package. However, the collection, management, and maintenance of the data and information from multiple departments and agencies require keen leadership and team-building skills, as well as significant staff resources to ensure that the data and information are kept up-to-date.

The performance of these systems often falls short of their true potential since each agency typically purchases software that is proprietary and not interoperable with those owned by other agencies; nor are the databases or application profile interfaces standardized, even within each agency. There are the occasional, well-executed, customized software codes that are interesting, such as click-on icons that call up windows containing live digital video feeds from remote locations overlaid on a GIS map that indicate latitudes and longitudes of the site and link directly into the

[100] See sample list of incident and disaster planning support systems software at: www.drj.com/vendor/drj5.html.

emergency bus routing plan for emergency evacuation. For the most part, however, the state of the art falls short of the level of interoperability needed that would enable the sharing of live and archived feeds from multiple departments or agencies needed to make the system truly useful.

It is likely that Web-based hosting of such data will soon provide an equipment and software platform for such systems to allow them to realize their true potential. However, the results will still fall short unless the agency can adequately populate the system with appropriate data and information.

6.6 Challenges and Lessons Learned

The major challenges and issues encountered in using ITS technologies for safety and security onboard transit vehicles for transit facilities include:

- Lack of interoperability between and among systems due to lack of equipment and data standards;
- Populating the systems with timely, accurate, and usable data and information requires keen leadership to engage regional partners in the effort. It also requires a sustained commitment to acquiring and maintaining the data and information so that they are available and reliable for managing incidents;
- Consistent use of address standards is vital for incident tracking and analysis;
- Analysis and geographic display of safety and security incident data is valuable in determining effective resource allocation (cameras, scarce security personnel, route and zone safety measures); and
- Having an overall plan that clearly identifies who does what, in what order, and under whose command, in the event of a major safety or security incident.

6.7 Agency/Vendor Examples

6.7.1 Video Assessment Systems—New Jersey Transit Corporation (NJT)

The state of the art in station and facilities safety and security technology is best illustrated at NJT, where an "intelligent video" assessment system has been in operation since 2004.

The main technology elements of the NJT intelligent video system include:

- More than a thousand cameras, some with pan-tilt-zoom features, installed throughout the entire state at virtually all NJT rail and park and ride stations;
- Digital video recorders located at various onsite facilities with enough storage capacity for at least 90 days of video;
- High-speed, wide area network providing real-time transmission of digital video so personnel with access rights can log on, view live or archived feed, select a

length of footage not to be overwritten, or pull footage back onto the central network; and

Software that enables automated, "intelligent" monitoring that triggers alarms for human assessment of the scene.

The safety and security benefits of the system are numerous. Streaming digital video from over a thousand cameras located throughout the state's rail and bus network allows NJT police to have "eyes" nearly everywhere. Since the system is Internet-based, video can be monitored and recorded by any first responder or intelligence/detective agency personnel with proper access credentials from any computer or PDA with an Internet browser. Fires, burglaries, assaults, vehicle accidents, and acts of vandalism can all be viewed, recorded and archived for subsequent investigations. With software applications that automatically count passengers, identify intruders, or trigger alarms when baggage is left unattended on a station platform, the richness of the data and information obtained by the system is compelling enough to internal and external stakeholders involved with safety and security that they are very interested in participating as "engaged stakeholders" in the refinement of existing uses and the development of new applications.

As described in Section 6.3.2 above, the success of the intelligent video assessment system at NJT is due to the quality of the hardware and software, as well as the engagement of internal and external stakeholders in the output of the system. Achieving this level of effectiveness requires managerial leadership to champion the endeavor, and sufficient staff resources to specify and deploy the system. The police chief and head of the Information Technology Department, with strong support from the agency's executive director, were instrumental in making the project a success.

6.7.2 Chemical Detection Systems — WMATA

The best example of the state of the art in chemical detection is at WMATA, where the PROTECT system has been monitoring five rail stations for chemicals likely to be used by terrorists against passengers and employees.

The system consists of chemical sensors and video cameras that send information to a control center for assessment and possible action. Live feed is also sent to related fire departments, the Department of Homeland Security, and to emergency operations centers in Arlington, Montgomery County, and the District of Columbia. The objective is to effectively identify chemical releases at a transit station to provide early crisis management. When an alarm is triggered by the sensors, the video cameras are programmed to pan-tilt-zoom in the direction of the alarm to enable visual verification of an incident.

The PROTECT system was also located at the Rail Operations Center in an attempt to leverage existing capital investments in computers, communications, and power, as well as to enable close coordination in the event of an incident. However, despite best efforts by both WMATA and the contractor (Argonne National Laboratory), it was not possible to leverage existing capital investments by WMATA in a significant manner because of the complexities of deploying and testing the system while rail operations were in service. Therefore, the system evolved as a nearly stand-alone operation with its own cameras, servers, power generation system, and communications cabling. Despite the redundancy, the operational coordination aspects have proven to work well.

PROTECT has been thoroughly tested, and the equipment and software are performing to specification. The sensors pick up suspicious odors and send alarms to the control center and the video cameras pan-tilt-zoom to the area where the odor was detected. From an IT infrastructure efficiency and effectiveness perspective, the system does not degrade the overall WMATA IT network. In addition, the video cameras help WMATA fight ordinary crimes such as burglaries and assaults, and assist firefighters by identifying the locations of smoke and flames.

The greatest challenge to successful deployment of the PROTECT system is the development of policies and procedures on using the technology. For example, who should get access codes to the information generated by the system? What actions should personnel be authorized to take in the event of an apparent attack? How does the agency deal with "false positives," as in the case where cleaning fluid had been spilled near a sensor?

In the next two to five years, WMATA will be expanding the PROTECT system to detect radioactive material used to make so-called dirty bombs. It will also be testing autonomous bio detection equipment that will significantly reduce the time needed to get samples tested for biological germs.

In summary, the technology exists for sensors and cameras to "see" chemical, radioactive, and biological materials. The real question is how will the agency be able to prevent perpetrators from setting them off; or, if faced with a real attack, a detonation, or release of a chemical or biological germ, what actions can and will be taken to minimize casualties and speed recovery?

6.7.3 Transit Mobile Broadband Communications—Cedar Rapids, IA

One of the most exciting developments in transit ITS is the implementation of a transit mobile broadband communications system in Cedar Rapids, IA. In this application, the overlay of an ITS system with extended features enabled by broadband at 1.5 mgbits per second onto a mobile broadband technology enables the agency to communicate voice and data transmission between vehicles (both fleet and supervisory) via a combination of Ethernet and broadband wireless LAN. As described earlier, this "enabling technology" provides seamless Internet access throughout a transit corridor, and thus a virtually endless variety of data and information packages can be communicated between and among the vehicles within the corridor.

From the transit agency's perspective, the security-related benefits of the broadband corridor include the ability to transmit live, streaming video for continuously monitored security assessments and to tap into a bus remotely to enable multimedia, control center-to-vehicle communications during a crisis.

Other operating benefits of the system include passenger counting using intelligent, video-based software; speedy information flows between the vehicle and back-office administration; and location-based communications to passengers concerning points of interest via high resolution video. Video-based, automated passenger counting information can also be monitored in real time by the control center to determine whether or not to add an extra bus.

From the customer's perspective, the system provides a seamless connection — even during the vehicle's maximum traveling speed — to the rest of the world via the Internet using any handheld PDA or laptop computer.

Future expansion of the system in Cedar Rapids beyond the initial test corridor is highly likely, with an endless number of Internet browser-based applications that can and will be made available to the agency and its customers. As more municipalities around the nation begin to deploy municipality-wide broadband Internet access systems for their citizenry, browser-based services will become more prevalent. With the advent of transit corridor broadband communications, citizens will still be connected when they get on their bus and during their travels.

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Chapter 7 Transportation Demand Management

7.1 Introduction and Technology Overview

As defined by the U.S. Department of Transportation, Transportation Demand Management (TDM) is "any action or set of actions aimed at reducing the impact of traffic by influencing people's travel behavior."[101] TDM, which includes all manner of public transit operations and incentives, is the "big picture" strategic solution for the day-to-day mobility problems that ITS was originally created to address. In that big picture sense, the state of TDM implementation itself defines the true "state-of-the-art" for ITS and transportation management in general. The state-of-the-art in TDM defines the extent to which transportation providers and travelers not only "do things right" tactically, but "do the right things" strategically as well.

Public transit is central to TDM, and TDM strategies naturally yield significant benefits for public transit. TDM strategies work hard to improve public perception and cost effectiveness. Examples include operations, information, and marketing strategies that increase transit utilization; experimental routes and feeder services that open new transit markets; and ridematch and telecommuting applications that reduce peak vehicle requirements.

Unlike supply-side solutions that seek to temporarily reduce congestion by adding capacity in reaction to existing or anticipated demand, a TDM strategy seeks to permanently change the nature, magnitude, and distribution of the demand for travel itself.[102] While supply-side solutions are focused on finding ways to move more vehicles, a TDM strategy is focused on influencing traveler behavior so that existing capacity can be used to accommodate more people.[103] Where supply-side solutions tend to involve small numbers of large projects aimed at regional needs, a TDM strategy is more likely to involve large numbers of relatively small projects tailored to local and individual needs.[104] TDM uses customized, even personalized, solutions to proactively influence travel demand, mode choice, and trip time, both pre-trip and en route. These innovative approaches are intended to cost-effectively minimize transportation cost and time without sacrificing personal mobility, thereby generating the greatest possible return on investment from the regional transportation infrastructure.

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101 "A Toolbox for Alleviating Traffic Congestion," Institute of Transportation Engineers, Washington, DC, 1989, p.107.

102 Hattum, David Van, "TDM Guidebook — Expanding Commuter Options in the Twin Cities: Practical and Cost-Effective Steps to Reduce Congestion by Optimizing Travel Demand Management (TDM) Strategies," 494 Commuter Services.

103 Ibid.

104 Ibid.

Transportation professionals implement TDM by creating options for route and mode choice by:

- Facilitating and influencing traveler decisions with respect to route choice, mode choice, and trip time;
- Encouraging greater vehicle occupancy (more people per car, van, or bus);
- Maintaining a balance between land development and transportation capacity;
- Strategically limiting new capacity to prevent unplanned induced demand; and
- Encouraging land development policies that minimize the underlying need for travel in the first place. [105]

In addition, TDM efforts have targeted parking policies and practices pertaining to parking availability, management, and costs.

The mission of ITS technology in supporting TDM is to generate and communicate management and control strategies that reduce the number of individuals who choose to drive alone, increase the use of high occupancy vehicles and public transit, and provide a variety of mobility options for those who wish to travel in a more efficient manner (i.e., during non-peak periods).[106] The National ITS Architecture lists two major functions for TDM, which are (1) Increase Efficiency of Transportation System and (2) Provide Wide Variety of Mobility Options.[107] Most transportation professionals also recognize an important third function, (3) Avoid Future Congestion.[108]

The first two of these ITS functions are supported by such conventional ITS applications as ramp metering, congestion pricing, high speed toll collection, high occupancy vehicle (HOV) lane management, multimodal traveler information, transit signal priority, highway advisory radio (HAR), and variable message signs (VMS). Also included are less conventional ITS applications such as pedestrian signal priority, regional parking management, dynamic rideshare, multimodal service coordination, and transportation alternatives marketing.

The third function, avoid future congestion, is supported by some of the more strategic ITS applications such as the ITS data warehouse and advanced travel demand modeling, as well as by transit incentive programs and various transportation avoidance technologies unrelated to ITS per se, such as the virtual office, telecommuting, and online shopping. Avoiding future congestion is also supported by

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[105] Ibid.

[106] Transportation Demand Management User Service, National ITS Architecture, US Department of Transportation, Washington, DC, 2005, www.iteris.com/itsarch/html/user/usr18.htm.

[107] Ibid.

[108] Institute of Transportation Engineers, op. cit.

a variety of nontechnical (i.e., legislative) growth management tools designed to ensure a healthy balance between transportation demand and transportation capacity.[109]

Technologies used in this third functional area certainly influence transportation demand. However, this report will not address them in depth because the technologies are more likely to be systems and programs that employers and retailers use to leverage the communications capabilities of the Internet, or database tools that support policy makers at a government level, rather than specific ITS technologies that can be controlled or operated by a public transit agency.

Specific ITS examples of TDM technologies and application examples relevant to public transit include:

- Internet (for itinerary planning, registration and activation, information dissemination, and inter and intra-agency communications);
- Computer Modeling (for planning and decision support);
- Data Warehousing (for planning and decision support);
- Computer Networking (for system integration and inter and intra-agency communications);
- Personal Digital Assistants (PDAs) (for pedestrian location and traveler information dissemination);
- Machine Vision (for parking management);
- Dedicated Short Range Communication (DSRC) (for use of electronic toll tag equipped vehicles as roadway performance probes);
- Variable Message Signs (VMS) (for dissemination of modal travel times, parking availability, and time of next transit departure);
- Highway Advisory Radio (HAR) (for dissemination of modal travel times, parking availability, and time of next transit departure);
- Electronic Payment (for ease of access to transit, itinerary activation, and verification of specific need for connection protection);
- Transit Advisory Radio (for dissemination of real-time status and parking information);
- Interactive Voice Response (IVR) telephone (for itinerary planning, registration and activation, and personalized information dissemination);
- Voice Recognition (for ease of access to transit information);
- Infrared Sensing (for sidewalk/crosswalk occupancy detection);
- 511 Traveler Information Portals and Services (for improved access to information);
- Automatic Vehicle Location (AVL) (for service status and real-time identification of needs for connection protection);

[109] Ibid.

Cellular Telephone (for traveler communication);
Mobile Data Terminals (for trip assignments, route guidance, and service coordination operating instructions);
Transit Signal Priority (TSP);
Integrated Corridor Management (ICM);
XM Satellite Radio (for information dissemination);
Geographical Information Systems (GIS) (for itinerary planning, information presentation, and decision support); and
Data Interface Standards and Protocol Converters (gateways) (to enable inter- and intra-agency data exchange).

Other non-ITS solutions that have demonstrated significant TDM benefits include:

8. Car-sharing where employers maintain (or subscribe to) a pool of vehicles to be used for business travel, thereby eliminating the necessity for employees to drive to work merely to have a vehicle available for work-related travel[110];
9. Parking cash out where employers who provide free parking offer the cash equivalent of the parking subsidy to employees who do not drive to work[111];
10. Employer-provided bus passes and bicycle amenities that allow employers to reduce single occupant vehicle travel while simultaneously saving money on parking lot operation and maintenance;[112]
11. Alternative work hours;[113]
12. Trip reduction ordinances;[114]
13. Negotiated demand management agreements;[115]
14. Transit-friendly site design to minimize traffic;[116]
15. Auto restricted zones;[117]
16. Growth management ordinances;[118]
17. Home office/telecommuting;
18. Feeder services;
19. Shuttles;
20. Parking management ordinances;
21. Multiple use zoning ordinances; and
22. Transit tax benefit programs (e.g., TransitCheck).[119]

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[110] Hattum, op. cit.
[111] Ibid.
[112] Ibid.
[113] Institute of Transportation Engineers, op. cit., p. 120.
[114] Op. cit., p. 122.
[115] Op. cit., p. 115.
[116] Op. cit., p. 114.
[117] Op. cit., p. 112.
[118] Op. cit., p. 108.
[119] www.transitcenter.com/.

The distinction between transit-related TDM and everyday transit operations is a fine one. For example, offering attractive and reliable transit headways and travel times is a basic tenet of everyday transit operations; it is also an enabling strategy for TDM. Effective marketing of transit services is an everyday business reality; it also is an element of TDM when influencing mode shifts from personal vehicles to transit. Fleet management and operations supervision is another everyday transit occurrence; it too becomes TDM when coordinated to enhance service and/or provide seamless connections across modes. With respect to transit, therefore, TDM is perhaps best characterized simply as "advanced transit operations and marketing."

For purposes of this report, advanced transit operations and marketing technologies applicable to ITS Transportation Demand Management have been divided into three major categories:[120]

Dynamic Ridesharing;
Automated Service Coordination; and
Multimodal Transportation Management Centers.

Concerning state of the art, little has changed with respect to ITS transportation demand management since the last State of the Art Report (Update 2000) was published. The sites listed at that time essentially retain that distinction today.

7.2 Dynamic Ridesharing

7.2.1 Technology Description

Dynamic ridesharing[121] services can run the gamut of technical complexity from manually operated call centers to fully automated, Internet-based ridematch[122] applications, and from personal automobiles to fully automated personal rapid transit (PRT).[123]

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[120] It should be noted that elements of various other ITS application areas, most notably traveler information, traffic control, electronic payment, fleet management, in-vehicle guidance, and the ITS data warehouse, when used effectively, may also support transportation demand management. These applications are typically not intended primarily for TDM, however, and so are addressed elsewhere in this report.

[121] Ride sharing is the act of sharing a vehicle with one or more other people.

[122] Ride matching is the process of pairing prospective passengers with available drivers with common origins or destinations.

[123] Personal Rapid Transit (PRT) is theoretically a highly efficient transport method that offers unscheduled on-demand nonstop transportation between any two points on an interlaced network of specially built guideways, using small (1-6 person) cars that follow mathematically optimized trajectories from point to point. (Wikipedia, http://en.wikipedia.org/wiki/Personal_rapid_transit).

In its ultimate form Dynamic Rideshare is essentially a low-cost paratansit service that provides a means by which two or more travelers can be joined in real time with others headed to, or past, the same locale with taxi like responsiveness.[124] The rideshare trip may start or end at an initial origin, a final destination, a transit stop, or an intermediate rideshare transfer point. It could also involve private automobiles, vanpools, paratransit vehicles, boats, and even light aircraft. Most common at present, however, are subscription ridematch[125] and shared paratransit services that use private carpools, private or corporate vanpools, and government-funded paratransit vehicles.

Subscription ridematch services are administered by hundreds of public and private Transportation Management Associations (TMAs) throughout the U.S., as well as by many state DOTs. Subscription ridematch services allow travelers (usually commuters) to register themselves as passengers, drivers, or both, and then match prospective drivers and passengers having common travel times, preferences, origins, and destinations. They are often supported by corporate sponsors who benefit from a reduction in required parking at their facilities. Most sponsored ridematch services also offer a guaranteed ride home in case of emergencies.

Shared paratransit services are typically operated by government entities (either in-house or through a contracted provider) that provide curbside pickup for multiple riders on preplanned routes that are "dynamically" programmed the day before. This type of next-day rideshare has found widespread use in satisfying the transportation needs of state and federal welfare, Head Start, disabled, and special needs programs throughout the U.S. They may also serve as feeder services for local transit facilities.

Obviously, the greater the number of travelers that can be carried in a given vehicle on a given trip without compromising quality of service, the more efficient and effective the rideshare operation becomes. One relatively recent innovation that has been successful in increasing capacity utilization for next-day rideshare is the merging of conventional subsidized paratransit services with full-fare subscription services to provide a guaranteed ride for nonsubsidized travelers. The idea is that if a vacancy exists on a subsidized paratransit vehicle, then it makes perfect sense to pick up a full-fare passenger or two (or six) along the way. Since the trip will run regardless, it may as well run with more passengers. Subscription riders in Massachusetts enjoy a high degree of satisfaction with the reliability, comfort, and convenience of the merged

[124] Many airport shuttle services operate in this fashion.
[125] In a subscription service, the ride matching process is accomplished well in advance of the trip; typically the subscription is for multiple repeated trips to/from the same location.

service; so much so that the subscription service must be managed to avoid oversubscribing spare paratransit capacity.

Proposed advanced versions of dynamic ridesharing also include Personal Rapid Transit (PRT)[126] and Autonomous Dial a Ride Transit (ADART). PRT is a theoretically highly efficient transport method that offers unscheduled on-demand, nonstop transportation between any two points on an interlaced network of specially built guideways separate from existing roadways. It uses small (1-6 people) cars on mathematically optimized point-to-point trajectories. ADART is a proposed method of dispatching and routing transit vehicles over the existing roadway network in real time that is theoretically more efficient than operating a conventional fixed-route transit line with extremely low ridership (as is often the case on mandated routes). Development projects are currently underway in both areas, including a partial ADART implementation in Corpus Christi, TX. However, fully functional and fully operational examples in revenue service do not yet exist in the U.S.

7.2.2 State of the Art

"Static" ridesharing and ride matching services have been in operation since before the 1970s. The current state of the art has achieved "next day" responsiveness (i.e., pairing riders with transportation providers on a flexible day-by-day basis), but true "dynamic" ride matching, (i.e., pairing riders with hosts in real time) has not yet been successfully implemented in the U.S.

State-of-the-art paratransit ridesharing services are currently distinguished by such features as:

- Automatic Web-based user registration;
- Automatic verification of trip eligibility (through integration with the agency's automated itinerary planning tool and eligibility databases);
- Next-day service;
- Automatic verification of service delivery (typically using coded subscriber ID cards and onboard card readers);
- Innovative use of supplemental subscription services to reduce subsidies;
- Dynamic allocation of individual trips to lowest cost operators on a day-to- day basis;
- Partnering (providing startup vehicles, umbrella insurance, communications, and administrative services) to encourage small operator participation; and
- Rigorous quality inspection and quality control to proactively ensure reliable service from contracted providers.

[126] (Wikipedia, http://en.wikipedia.org/wiki/Personal_rapid_transit).

State-of-the-art sponsored carpool and vanpool ridematching services are currently distinguished by such features as:

- Automatic Web-based user registration;
- Guaranteed ride home;
- Automated quality control surveys; and
- Automatic verification and purging of inactive participants.

Examples and characteristics of state-of-the-art dynamic ridesharing and ridematching deployments found in transit include:

- Montachusetts Area Regional Transit, Fitchburg, MA
  - System allows management of transportation brokerage for 75% of the state (most of Massachusetts except for Cape Cod and the Boston Metropolitan Area).
  - Provides 11,500 trips per day with over 150 vendors and 600 vehicles.[127]
  - Coordinates with commuter rail and intercity buses, and provides feeder services and parking.
  - Working toward utilization of commuter rail for long-haul trips, using paratransit for relatively short distance carriage at origin and destination only.
  - Conventional paratransit was merged with full-fare subscription service, which delivered an operating cost reduction of 60% with no impact on quality of service.
  - Subscription service is especially popular for transporting young children to schools where conventional fixed-route transit typically involves multiple transfers or extended walking distances.

- MTA, Los Angeles, CA.
  - Automatic paratransit eligibility verification.
  - Automatic paratransit service delivery verification.

- New Jersey Department of Transportation, Trenton, NJ
  - DOT-sponsored portal to Transportation Management Associations statewide (www.njcommuter.com).
  - Statewide ridematching service.

7.2.3 Emerging Trends

As vendors have developed more capable flex routing systems, and more and more operators have equipped their vehicles with various forms of communications and

[127] "APTS State of the Art Update 2005" Web survey, Palisades Consulting Group, 2005.

location tracking technologies, the lead time required for trip requests continues to drop. Additionally, a growing number of states are taking advantage of Internet technology to facilitate statewide ridematching. In Corpus Christi, TX, where a simplified partially autonomous dial-a-ride transit (ADART) implementation is currently operational, progress continues toward development of a fully functional ADART service designed to replace underutilized fixed-route transit services with paratransit vehicles dynamically scheduled in real time.[128] Perhaps the most dramatic development, however, is the certification in the United Kingdom of what may become the world's first economically viable personal rapid transit (PRT) application, due to begin pilot implementation at London's Heathrow Airport later this year.

7.3 Automated Service Coordination

7.3.1 Technology Description

Automated Service Coordination refers to advanced transit operations technologies, policies, and procedures designed to guarantee or "protect" passenger transfers between the various vehicles and services that may comprise a fully linked trip. In this usage, it is also sometimes referred to as "automatic connection protection." A second usage of the term applies to automatic headway coordination among two or more different service providers along a common operating corridor.

Service coordination could occur between different vehicles of the same mode, different modes, different agencies, and even different sectors of the transportation industry. Supported transfers could include connections between bus, rail, paratransit, ferry, rapid transit, vanpool, taxi, commercial airline, and others. Even the connections from pedestrian segments of the journey might be conditionally protected as well (i.e., when PDAs and cell phones become more universally GPS enabled), especially in areas where headways are significantly long.

Scheduled connections are planned at a policy level (where schedulers design planned connections into the service) and executed at the operational level (where dispatchers ensure that vehicles do not depart from a planned connection point until their connecting trips have arrived). Scheduled connections may be protected unconditionally as a matter of agency policy, or conditionally as part of managed strategy to optimize service quality and effectiveness on a trip by trip basis.

Automatic Service Coordination systems use ITS technologies such as AVL, electronic fare collection, decision support systems, and mobile data terminals to:

Identify and/or confirm the existence of a desired transfer;

[128] http://www.its.dot.gov/resources/IntegrationProject/projects/PTO-72.htm

Identify the need for coordination and intervention;

Weigh the operating and passenger impacts — both immediate impacts and likely downstream impacts — of delaying or not delaying, expressing, or rerouting one vehicle to protect a planned connection with another;

Communicate coordination requests to the agencies and vehicles involved;

Receive confirmation that coordination will or will not be provided;

Effect, facilitate, and monitor coordination;

Provide notice to affected passengers as to whether their planned connection will or will not be honored and, if not, how long they should expect to wait for the next connection to their planned destination; and

Evaluate overall effectiveness of connection protection actions (or inactions) taken.

Different implementers have used different methods for identifying and confirming the existence of a desired transfer. In some cases, the need for connection protection at a given transfer point is simply assumed based on historical data or anecdotal observation.[129] In others, a vehicle operator manually initiates connection protection for a specific trip based on a specific request from a specific passenger.[130] In yet other cases, in airline transportation, for example, service coordination is tied to confirmed traveler itineraries.

One passenger information and customer resource management technology common in airline transportation, and just now being considered for public transit, is Itinerary Tracking, which also has promise for identifying specific connections that may need to be protected on a given day. Itinerary Tracking allows individual travelers to register individual itineraries (via Internet or telephone), determines how known delays and incidents are likely to affect each individual itinerary, and generates customized real-time status and connection information for each individual registered customer. The same registered itinerary that drives the Itinerary Tracking application can also be used to identify specific connections that may need to be protected. In addition, a properly integrated electronic fare collection application offers yet another opportunity for real-time confirmation that a given transfer may need to be protected. To date, however, there are no reports of agencies having actually tied a fare collection or itinerary tracking system to a service coordination function to automatically identify and confirm a specific need for connection protection on a specific trip.

[129] Battelle Memorial Institute, "Evaluation of Utah Transit Authority's Connection Protection System, Final Project Report," FHWA, document 14074, May 2004. www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE//14074.htm.

[130] USDOT, "AATA AOS Evaluation – Transfer and On Time Performance Study: Before and After AOS Implementation." www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/13147.pdf.

7.3.2 State of the Art

Automated Service Coordination for public transit is still in its infancy in the U.S. Unconditional connection protection is commonplace, especially for commuter rail,[131] while conditional protection is not. Current systems do operate in real time using actual vehicle location information, but instead use relatively simplistic decision-support tools for determining the method and desirability of intervention to protect a particular connection. No one implementation has yet pulled together a complete, fully optimized package — from identification, through confirmation, evaluation, response, and followup — and there are no reports of any application that has attempted to automatically protect connections between services operated by two or more different agencies.[132]

Systems deployed to date have met with varying degrees of success. While passengers and operators do find value in Automated Service Coordination technology, there are a number of common complaints. The most common complaints are:

- That vehicles are sometimes held unnecessarily to protect planned connections that no passengers actually intend to use on the specific trip in question;
- That vehicles are sometimes prematurely instructed to delay departure from an upcoming transfer point when in fact the connecting vehicle will actually arrive on time; and
- The act of holding a vehicle to protect a connection at one location can often generate additional missed connections further downstream if done without proper consideration for the "big picture," especially where the slack in scheduled running times is insufficient to accommodate minor delays.

State-of-the-art Automated Service Coordination systems are currently distinguished by such features as:

- Real-time identification of specific needs for intervention to protect planned connections; and
- Real-time delivery of connection protection instructions to affected vehicles.

Additionally, several transit agencies have implemented auto-dial or e-mail notification capability to alert subscribing customers of service disruptions and delays relevant to their usual itineraries.

Examples and features of state-of-the-art automated service coordination deployments found in transit include:

[131] Examples include MTA Metro North and Long Island Railroads in New York City, NY.
[132] APTS State of the Art Update 2005 web survey, Palisades Consulting Group, 2005

Utah Transit Authority, Salt Lake City, UT

600 vehicles equipped.[133]

Connections protected for transfers from light rail to bus.

Specific target locations are selected based on expected transfer points.

No real-time confirmation of numbers of passengers actually intending to transfer.

Ann Arbor Transit Authority, Ann Arbor, MI

91 vehicles equipped.[134]

Manual initiation of connection protection by bus operator in response to specific requests from passengers.

7.3.3 Emerging Trends

Decision-support systems used to determine the desirability of providing connection protection in a given case are getting "smarter" with each new implementation, and ties to automatic passenger counting (APC) systems to aid in determining the actual impact of providing protection (or not) are becoming more common. The next generation of these tools is expected to include:

64. Consideration of effective headway in determining whether or not intervention is actually necessary, and which vehicle's schedule should be modified (i.e., that of the vehicle being transferred to, or that of the vehicle being transferred from), and what form that modification should take;
65. Consideration for downstream impacts of intervention at a given location;
66. Consideration for numbers of passengers likely to be impacted by protecting or not protecting a given connection based on historical or APC ridership data;
67. Cost-based optimization based on total passenger-minutes of delay, including additional waiting time for the next trip if the connection will not be protected; and
68. Real-time identification and verification of the need to protect a specific connection based on electronic fare collection and/or itinerary tracking data.

7.4 Multimodal Transportation Management Centers

7.4.1 Technology Description

A Multimodal Transportation Management Center refers to a collection of traffic and transit operations centers that have been linked together to facilitate optimization of regional network performance across multiple transportation modes. Cooperating

[133] USDOT, ITS Deployment Statistics 2004 — Utah Transit Authority. http://itsdeployment2.ed.ornl.gov/its2004/AdminViewSurvey.asp?SSN=TMandAgencyID=1590.

[134] USDOT, ITS Deployment Statistics 2004 — Ann Arbor Transit Authority. http://itsdeployment2.ed.ornl.gov/its2004/AdminViewSurvey.asp?SSN=TMandAgencyID=552.

modes could include highway, bus, rail, intermodal freight, and ferry. Cooperating agencies could include transit operators, freight terminals, highway operators, public safety organizations, ferry operators, parking operators, airport operators, and bridge and tunnel operators. Cooperating centers could be physically co-located, or merely electronically linked.

Multimodal transportation management seeks to transcend institutional boundaries between the typically distinct, often sub-optimized fields of transit management, traffic management, parking management, and incident management to provide a more efficient regional transportation network, and a less costly, less frustrating travel experience for commercial shippers and the traveling public alike.

While the initial focus of a regional management system may be limited to incident management alone, important as it is, much more can be accomplished as parking and transit operations are factored into the mix. Integration of parking management will enable transportation agencies to inform travelers of not only where available capacity exists, but equally important, when that capacity is expected to be exhausted and whether there will be available capacity by the time the motorist arrives.

Multimodal Transportation Management technologies include:

8. Variable Message Signs;
9. Electronic Toll Collection;
10. Freeway Ramp Metering;
11. Transit Signal Priority;
12. Ramp Meter Bypass;
13. Interagency Data Exchange;
14. Video Surveillance;
15. Video Data Exchange;
16. Roadway Performance Monitoring;
17. Automatic Vehicle Location;
18. Electronic Payment;
19. Machine Vision;
20. Wireless Communications;
21. Internet;
22. Cellular 511;
23. Highway Advisory Radio;
24. Electronic Vehicle Identification;
25. XM Satellite Radio; and
26. Decision Support Systems.

Multimodal transportation management centers use these technologies to monitor highway and transit performance to detect incidents and congested conditions, notify affected agencies, identify available assets, coordinate a unified response, and track results. The distinctive element of multimodal transportation management, as opposed to traffic, transit, parking, or incident management alone, is that the identification of available assets and coordination of a unified response is carried out in a cooperative manner by all the agencies involved. Applications include:

- Data from multiple sources can be integrated automatically to speed detection and confirmation of incidents;
- Incident response assets of different agencies can be operationally pooled to speed incident confirmation and response;
- Assets from multiple agencies can be operationally integrated to provide coordinated regional disaster response;
- Transit information displays can be used to quickly disseminate Amber Alert missing persons information throughout the region;
- When a traffic incident reduces highway capacity, affected transit operators can be quickly notified, and viable alternative routes and available transit services can be quickly identified and relayed to motorists via variable message signs and highway advisory radio;
- Planned disruptions and events such as construction activities can be coordinated across multiple modes and agencies to prevent undue impact on the traveling public;
- Differences in route segment speeds or travel times for different routes and modes can be clearly illustrated on integrated regional maps in real time to allow travelers to make informed mode and route choice decisions;
- When parking areas downtown are full, motorists can be quickly directed to suitable park and ride facilities with known available capacity;
- Where roadways lack dedicated performance monitoring equipment, transit and commercial fleet operators can fill these information gaps using AVL-equipped vehicles as autonomous probes to measure and report roadway performance;
- When unexpected icing or other adverse conditions are detected at a specific location, transit agencies and trucking operators can be quickly notified and drivers warned appropriately;
- When transit vehicles are running behind schedule, traffic signals can be instructed to provide conditional priority;
- When a large platoon of vehicles is exiting a rail park and ride facility following arrival of a train, traffic signal timing can be proactively adjusted to optimize roadway performance; and
- When movement of a train will interfere with planned traffic flows, traffic signal timing can be dynamically coordinated with train speed to minimize unnecessary impacts on signal coordination.

7.4.2 State of the Art

Like "transportation management," the phrase "multimodal transportation management" has come into common usage in contexts that fall far short of its original intent. A quick search of the Internet will indicate that nearly every state has something they call a "Multimodal Transportation Management System," yet few if any have something that can perform the kinds of operations described above. Although several very promising, very successful applications do exist, much work still remains.

In general, present-day "multimodal transportation management centers" are at best actually more appropriately termed "multimodal transportation information portals," entities that serve the valuable purpose of relaying reported incident information to affected agencies but are not equipped or staffed to support the close coordination required to continually optimize regional network performance on a day by day, minute by minute basis.

One very notable exception is TranStar, the transportation and emergency management center for the greater Houston, TX, region. TranStar combines traffic, transit, and emergency planning and management under a single overall operating entity.[135] Even in an operation as advanced as TranStar, however, there is room to add parking management and rail coordination to the list of transportation issues still to be addressed.

At present, parking management is still very much an evolving piece of the puzzle. Concern about parking availability at rail stations and park and ride lots may be all it takes to prevent motorists from trying public transit. The ability to acquire and display real-time parking information at an individual lot is relatively common throughout the country.[136] Collection and integration of parking information from multiple lots for regional parking management, however, is not.

Currently, notwithstanding localized implementations at some national parks and theme parks, no truly regional deployments of real-time regional parking information systems have been reported in the U.S. The current state-of-the-art in regional parking information systems that have actually been successfully deployed in the U.S. appears to be limited to the provision of static lot capacity information only.

Another area that is still evolving is that of integrated information display for support of the pre-trip mode and route choice decision. Integrated display of historical transit

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135 ITS International, "Star of the Lone Star State," Kent, UK, 2005.

136 Nationwide, 12 of 106 metropolitan areas surveyed report use of dynamic message signs to display parking information at one or more individual lot locations (ITS deployment survey 2004; http://itsdeployment2.ed.ornl.gov/its2004/Results.asp?ID=971.)

and highway performance and reliability on a single regional map has not yet been attempted in the U.S.

State-of-the-art multimodal transportation management is currently distinguished by such features as:

- Static regional parking information;
- Use of AVL-equipped buses as probes for roadway performance monitoring on arterial roadways;
- Use of electronic toll-tags for roadway performance monitoring on freeways;
- Transit signal priority;
- Integrated incident detection, verification and response;
- Integrated weather and roadway condition reporting;
- Integrated construction and event planning;
- Integrated flow mapping and travel time calculation;
- Links to regional real-time transit status;
- Regional itinerary planning;
- Shared real-time video;
- Multilingual information; and
- Wireless information access.

Examples and features of transit related state-of-the-art multimodal transportation management centers include:

- Houston TranStar, Houston, TX
  - Co-located — physical center
  - Four agencies
  - 300 miles of fiber optic cable
  - 150 dynamic message signs
  - 1,600 buses
  - 18 light rail vehicles
  - 40 roadway weather information stations
  - 100 miles of high occupancy vehicle (HOV) lanes
  - 350 video surveillance cameras
  - 12 highway advisory radio (HAR) sites
  - 200 miles of automatic vehicle identification (AVI toll tag) roadway monitoring
  - Regional incident management system
  - Rail crossing monitoring system
  - Freeway interchange truck rollover warning system

Los Angeles County Metropolitan Transportation Authority, Los Angeles, CA
Advanced Transportation Management System provides infrastructure for planned multimodal transportation management and support to ongoing efforts toward regional traffic, transit, and incident management.[137]

Oregon Department of Transportation[138]
Integrated roadway status, weather, and construction information.
Statewide rideshare portal.
Statewide links to transit schedules (no itinerary planning).
Links to adjoining states' information portals.

Washington State Department of Transportation[139]
Real-time statewide video images.
Real-time flow maps and travel times.
Links to real-time transit status.
Statewide links to transit itinerary planning tools.

Regional Transportation District, Denver, CO[140]
Real-time bus and rail information.
Regional park and ride parking capacities (static information).
Itinerary planning.
Internet, PDA, and cell phone accessible.
Multilingual (English, Spanish, Italian, French).
TDM initiatives.

TRANSCOM, Jersey City, NJ
Tristate multimodal transportation information portal for the New York metropolitan area.
Hybrid architecture — virtual center with physical hub.
16 agencies.
Roadway performance monitoring using electronic toll tag readers.
Interagency regional video network.
Real-time regional traffic conditions.
Near-real-time regional transit conditions.
Regional itinerary planning.

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137 Palisades, op. cit.
138 ODOT Trip Check, www.tripcheck.com/Pages/BusRailEntry.asp.
139 www.wsdot.wa.gov/.
140 www.rtd-denver.com/.

7.4.3 Emerging Trends

Prototype demonstration projects for real-time public transit parking information systems have been initiated by the RTA in Chicago[141] and in Montgomery County, MD. If successful, corridor demonstrations such as these may pave the way for U.S. deployments of real-time regional parking information systems.

7.5 Challenges and Lessons Learned

7.5.1 Dynamic Rideshare Lessons Learned

Paratransit services traditionally require greater operating subsidies than other transit services, but integration of paratransit with supplemental subscription services that fill underutilized capacity with full-fare passengers have been found to dramatically improve net operating results (on the order of 60%) with no degradation of service.

ITS training for paratransit contractors is lacking, making it difficult for them to implement and maintain leading edge ITS technologies in a knowledgeable way. Contracting agencies can mitigate this issue by implementing appropriately designed and staffed technical assistance programs.

Rideshare services are best provided by small local operators dynamically competing for trip assignments on a day by day basis, but the cost of initial vehicle procurement, insurance, and administration can be a significant barrier to small operators seeking to enter the market. A modest investment in start-up vehicles, communications equipment, ITS training, administrative support, and quality control staff can pay long-term dividends many times over.

The onboard components of an advanced paratransit operations system may require greater electrical capacity than is commonly installed in light-duty vehicles. Paratransit operators can expect an abnormally high degree of failures when attempting to retrofit vehicle location, fare collection, card reader, and/or communications equipment onto existing vehicles not specifically equipped with the heavy-duty batteries, alternators, and onboard electrical management systems required to support them.

Fraud has proved to be an issue for some contracted paratransit services, where agencies have been billed for ineligible trips, for trips that were never delivered, and for trips delivered to fictitious "phantom" riders. Automated back-office verification processes using coded subscriber ID cards and onboard card readers can minimize the impact of this kind of problem.

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[141] Chicago RTA, ITS Program, Parking Management Guidance System (PMGS), www.rtachicago.com/CMS200Sample/uploadedFiles/its%20for%20web%20FINAL.pdf.

GIS-based paratransit and ridematching software systems need a detailed, accurate base map complete with transit routes, stops, park and ride locations, and other facilities added and maintained on a continual basis. This data maintenance effort should coordinated, if possible, with other modes and agencies to avoid duplication of effort and inconsistency in inserting new streets, correcting address ranges, and inserting transit features. Additionally, many other TDM databases such as the Trip Reduction Act, Employer Pass Sales programs, Ridematch locations, and Customer Relationship Management are most usable and maintainable when coordinated across multiple departments, modes, and agencies. Chapter 1, Integration, addresses these issues in detail.

7.5.2 Automated Service Coordination Lessons Learned

Automated Service Coordination, done correctly, while not the most technically demanding, is perhaps the most complex transit ITS application yet conceived, and arguably is more complex than the intelligent vehicle and the automated highway. When properly balanced and constrained to prevent undue impact on downstream transfers and non connecting passengers, Automated Service Coordination provides benefits to travelers (through improved service reliability) and also to operating agencies (through improved vehicle utilization, employee satisfaction, customer satisfaction, and customer loyalty). Although the benefits are real, proper balance can be difficult to achieve and even more difficult to assess.[142]

Automated service coordination deployments to date have universally neglected the need to gather information to evaluate their effectiveness on a day to day basis. Agencies need specific information to enable them to determine whether the system is actually improving their operations or making them worse, and under what conditions. The Battelle Institute study[143] on this subject is required reading.

7.5.3 Multimodal Transportation Management Center Lessons Learned

The extraordinary complexity of coordinating and maintaining multimodal transportation information at a regional Web site that is comprehensive, accurate, and user friendly cannot be overstated. The great majority of the planning that should go into such a system needs to be in the areas of data maintenance (a reliable process for receiving updates from participating agencies), data validation (ensuring that updates contain all the required data, in the correct format), and data synchronization (ensuring that all the correct information is available for a given day). Unfortunately, most project plans to date have tended to grossly underestimate the effort required in these areas (by

[142] Battelle, op. cit.
[143] Ibid.

as high as three or four times the original estimate), focusing instead on the itinerary planning engine and the user interface itself.

Various agencies, of various modes, have cited institutional issues that have slowed the development of multimodal transportation management centers, not only across different agencies (transit versus highway, or toll authority versus DOT), but across different modes within a given agency (bus versus rail) as well. This is not surprising given that agencies are not typically evaluated or rewarded based on their cooperation with others. Based on similar cases from the conventional business management literature, it appears reasonable to expect that the development and publication of summary performance measures and management incentives that track and reward overall transportation efficiency and effectiveness at the state or Metropolitan Planning Organization (MPO) level without distinguishing individual modes or agencies could be a useful tool in promoting an enhanced sense of multimodal interagency teamwork in this area.

As noted in State of the Art Update 2000, most metropolitan areas appear to be leaning toward the creation of "virtual" regional transportation management centers (i.e., individual agencies linked electronically) rather than new co-located facilities. It should be noted, however, that quality of service on an unhardened communications link may be subject to compromise, especially in times of natural or man-made disaster when a closely coordinated response is likely to be needed the most.

The co-located facility is believed by many practitioners to offer better coordination during emergency situations and major incidents when traffic needs to be diverted than is likely in a "virtual" center, but this improved coordination may carry with it the additional risk of a single point of failure for an entire region. The optimum balance of cost, scale, performance, survivability, and reliability has yet to be determined.

Most transportation professionals believe that mode and route choice decisions are made based on differences in the perceived convenience, cost, reliability, and performance of the various options available, yet no effort has yet been made to facilitate travelers' ability to actually make this comparison across modes. Every "multimodal" transportation information system deployed to date has been built in such a way as to prohibit co-mingling of performance information from different modes on a single map display. Travelers are shown transit or highway information, but never both on the same display. Implementers should consider facilitating an informed mode choice decision through development of performance and reliability measures that are consistent for both roadway and transit, with concurrent display on a single regional map.

The leap from information portal to integrated management center is a big one. It is best made incrementally, one application at a time. A logical first step is the integration of geocoded traffic status and incident information into a bus Computer Aided Dispatch (CAD) application in return for probe-derived roadway performance data.

7.6 References

Battelle Memorial Institute. "Evaluation of Utah Transit Authority's Connection Protection System, Final Project Report," Federal Highway Administration Report 14074, May 2004. www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE//14074.htm.

"Mobility Services for All Americans" (MSAA), www.its.dot.gov/msaa, and "United We Ride," www.unitedweride.gov. These two USDOT-led initiatives focus on enhancing human service transportation coordination and delivery, including using ITS to facilitate dynamic rideshare and single point of service access.

Chapter 8 Intelligent Vehicle Systems

8.1 Introduction and Technology Overview

From its modest beginnings under the federal Intelligent Vehicle Initiative (IVI), the development of Intelligent Vehicle Systems (IVS) technologies has expanded from a federal "initiative" to a much broader role that provides transit with core business tools. As a result of these efforts, state-of-the-art intelligent vehicle systems now provide transit with advance warnings of impending mechanical and electrical failures, integrated single-point operator sign-on of various onboard systems, management of onboard devices, adaptive vehicle control, route guidance, rear-end collision warnings, and automatic next-stop annunciation for passengers. Additional transit applications expected to be deployed in the near term include automatic detection of under inflated tires (a leading cause of premature tire failure), low visibility vision enhancement, lane-keeping assistance, and automatic driver impairment detection.

"Intelligence" in an onboard vehicle system implies the capacity to acquire and apply knowledge, the ability to cope with demands created by novel situations and new problems, and to apply what is learned from experience as effective guides to behavior.[144] Through the use of electronics, intelligent onboard systems automatically acquire relevant data from internal sensors and other systems throughout the vehicle and the surrounding environment. These advanced onboard systems then compare and process those data to create actionable information, coordinate responses with other systems, monitor the correctness and effectiveness of those responses, and modify subsequent processing and responses accordingly. It is the cooperative and interactive aspects of these systems that distinguish them from their "less intelligent" or "dumb" predecessors, which were limited by simple programming and lack of standardized interfaces.

For purposes of this report, IVS have been divided into three major categories:

- Onboard Integration
- Advanced Vehicle Safety Systems
- Vehicle Guidance/Automation

"Onboard Integration" has been further divided into "Intelligent Onboard Bus Integration" and "Intelligent Rail Vehicle Integration."

Examples of IVS technologies include:

- Global Positioning System (GPS)-based route guidance and navigation;

[144] *American Heritage Dictionary*, Houghton Mifflin Company, Boston, MA, 1985.

Communications-Based Train Control (CBTC);
Digital onboard Vehicle Area Networks (VAN) and Trainline networks;
Short-range wireless communications;
Mobile Data Terminals (MDT);
Multiplexed electrical systems;
Adaptive braking;
Adaptive traction control;
Adaptive cruise control;
Adaptive power management;
Infrared vision enhancement;
"Heads Up" Displays (HUD);
Wheel/tire temperature and air pressure monitoring;
Precision steering and docking;
Onboard Supervisory Control and Data Acquisition (SCADA);
Short-range Radio Direction and Ranging (RADAR) proximity sensing;
Short-range ultrasonic proximity sensing;
Machine vision; and
Interactive electronic defect card.

Intelligent Vehicle Systems interact cooperatively with other systems onboard the vehicle, with wayside systems, and ultimately with onboard systems of other vehicles to provide benefits that could not be otherwise achieved with stand-alone equipment. For example, IVS applications could ultimately reduce bus fuel consumption, maintenance costs, and running time variation by:

Determining the vehicle's expected time of arrival at an upcoming intersection (taking into account past history, current speed, traffic levels, and active stop requests);
Communicating with the wayside traffic signal controller to request priority handling at a particular intersection;
Determining in advance what signal will actually be displayed at the time the vehicle is expected to arrive; and
Informing the operator whether it would be advisable to maintain speed or decelerate for an expected stop signal.

Integration with an adaptive cruise control capability would then not only notify the operator, but also would automatically slow down the vehicle.

IVS applications also could ultimately alert the operator of fatigue or impairment, adverse trends in vehicle condition, and deviations from scheduled times and headways. These systems could also assist the operator in keeping the vehicle centered within the lane and maintaining a safe distance from the vehicle ahead, thereby avoiding impending collisions.

Similarly, IVS on a commuter train or rapid transit vehicle could ultimately reduce energy costs by coordinating traction power draw with that of other nearby trains to minimize peak load on the overhead catenary (electrical power supply), while simultaneously determining expected times of arrival at upcoming grade crossings, and then communicating with automatic grade crossing controllers to allow coordination of traffic signals to minimize disruption of local traffic flows. Onboard components could also monitor vehicle condition and note, for example, doors and equipment that the crew has had to "cut out" or bypass because they require maintenance or repair.

All of the scenarios described above are possible with available IVS technology. To date, however, U.S. transit agencies have explored only a few of the possible applications. The following sections outline the current state of the art in actual IVS deployments as well as emerging IVS trends.

8.2 Intelligent Onboard Bus Integration

8.2.1 Technology Description

Intelligent Onboard Bus Integration provides the means by which various stand alone equipment modules found on a transit bus can be made to interoperate with each other. The ability of this equipment to work together maximizes the functionality, reliability, usability, efficiency, and effectiveness of the overall transit operation, while minimizing total life cycle cost (LCC). Moreover, effective onboard system integration that results in fewer and simpler user interfaces will also be the key to realizing potential improvements in vehicle safety by facilitating driver acceptance of a wide variety of ITS collision avoidance technologies.[145]

Intelligent Onboard Bus Integration comprises a family of enabling technologies that operate at the top level of an onboard architecture, linking major electronically controlled components through a common communications protocol or "language" understood by all equipment on the network. The enabling technologies include digital networks, standard interface profiles, and computer software drivers that translate messages between the standard language of the network and the native language of a given electronic device.

[145] "Consumer Acceptance of Automotive Crash Avoidance Devices," Charles River Associates, Boston, MA, 1998.

For communications that take place below the top levels of the architecture, almost any network protocol will do. For example, for an Automatic Passenger Counter (APC), it may not matter what protocol is used to send information between the passenger count sensor and the device that first interprets the sensor's output into discrete boardings and alightings, if that device lies between the sensor and the vehicle network. Most modern vehicles host at least four distinct "non-standard" or "proprietary" interface profiles at this level for communicating raw data between the various subsystem components. These interfaces are often built on a general purpose interconnection technology such as Electronic Industries Alliance (EIA) RS232, RS422, or RS485, with little or no adverse effect on system integration.

However, for the processed APC boardings and alightings to be integrated with a vehicle location component and stored by an onboard event recorder to provide an account of passenger activity at each specific bus stop, a standard interface that allows messages to be clearly understood by each involved system is critical. In addition, if the network is to freely support components from different manufacturers, it is also essential that this standard interface be "open," meaning that it is thoroughly documented, unrestricted, and usable by all.

Currently, the most commonly used open network technology for state-of-the-art intelligent onboard bus integration is one built on the Society of Automotive Engineers (SAE) J1708 standard for serial data communications between microcomputer systems in heavy duty-vehicle applications.

Control for engines, transmissions and antilock brake systems (ABS) (i.e., the vehicle, "powertrain") has shifted exclusively to the much faster SAE J1939 network due to the safety-critical nature of the communication (i.e., the need for ABS to react quickly once a locked brake is detected). All major equipment vendors and bus manufacturers, however, still support a J1708 data interface because the speed of the J1708 interface is considered sufficient for non-powertrain related data communications. Given that J1708 can also be used like a "gateway" that grants access to devices that need powertrain data, and since a large installed base of J1708-based monitoring components and diagnostic equipment already exists in the commercial trucking industry, use and availability of SAE J1708 devices is expected to continue for the foreseeable future.

Likewise, multiplex suppliers who provide microprocessor-based systems that control basic onboard electrical functions such as activating lights and door interlocks may typically use a proprietary data network to achieve that control, but often offer an optional SAE J1708 interface to provide integration with other onboard systems.

State-of-the-art light rail applications, which are most often patterned after bus rather than heavy rail transit, also typically employ the SAE J1708 standard for digital communications between onboard subsystems, and tend to share common communications, vehicle location, passenger counting, and passenger information equipment with their bus counterparts.

Less common is the Information Technology (IT) industry standard "Ethernet," which can be used in wireless, wireline, and fiber optic implementations using easily readable Extensible Markup Language (XML) text files to convey messages between onboard components. Wireless Ethernet technology is currently the emerging industry standard for vehicle-to-wayside communications, and is commonly used for such automated garage-based applications as upload of sign and schedule tables and download of event recorder, vehicle health monitoring, and passenger count data. The use of Ethernet for onboard communications may also grow if strong IT departments are successful in driving their agencies away from J1708 in favor of an IT-managed personal computer (PC) onboard operating system model.

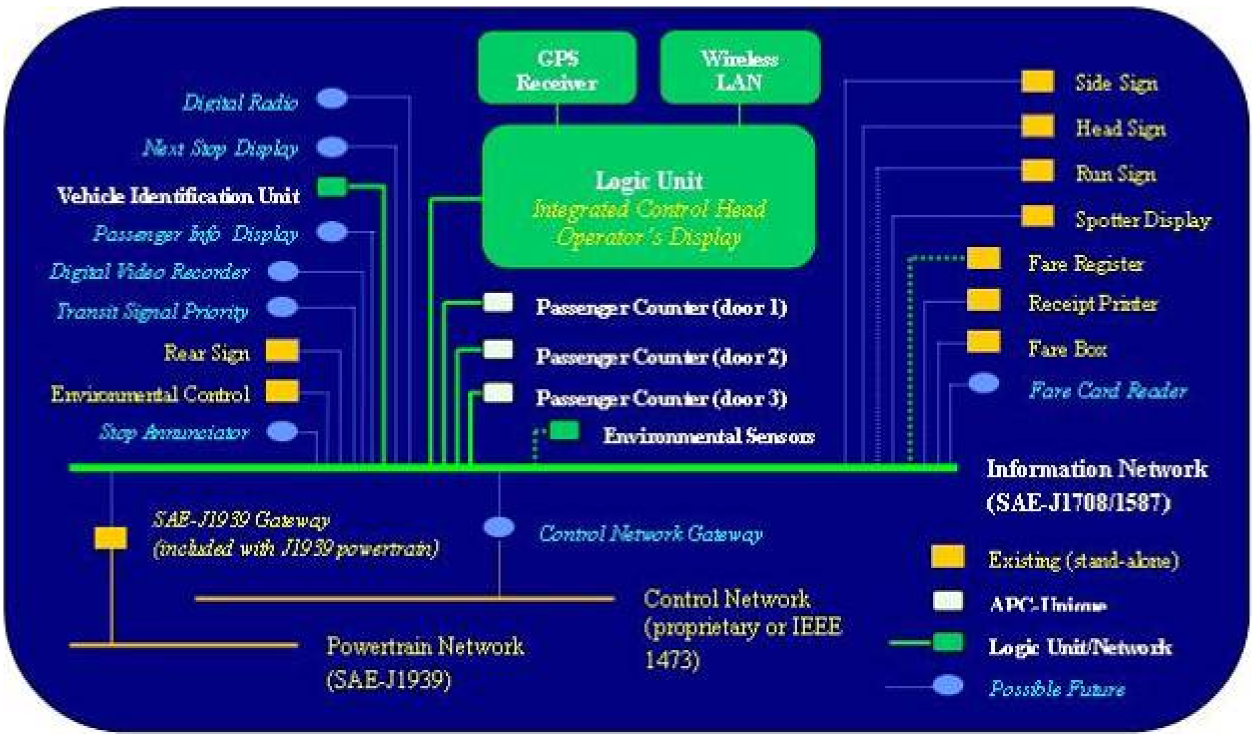
Additionally, where network communications are required to span a particularly difficult wiring environment, for example in retrofitting an articulated bus or light rail car, agencies can expect increased use of the "Bluetooth" short range wireless connectivity standard.

All of these standard networks are complimented by standard interface profiles that provide recommended data definitions and messages for use on the network. The SAE J1587 recommended practice for electronic data interchange is one such interface profile that many readers may be familiar with because it is designed for use with the SAE J1708 network. SAE J1587 defines standard message identifiers (MIDs) and parameter identifiers (PIDs) that clearly indicate the type of data requested and the value, unit, and context of the information being conveyed in return. By using these defined profiles as a starting point, interface software within a network-enabled device can easily interpret between the standard messages on the network and whatever communications scheme may be native to the respective device.

The great majority of recent system implementations have included some degree of onboard system integration across a standard network. Most common is integration between an AVL system, the powertrain, and an automatic passenger counting (APC) system to provide an event logging function that captures time-stamped vehicle condition, ridership, and vehicle position information for offline analysis. Somewhat less common at present, but becoming more commonplace in state-of-the-art deployments, is the addition of stop annunciation, destination sign control, digital video recording, and fare collection to provide single-point operator sign-on for all onboard systems.

Figure 21 illustrates a possible migration path to a nearly fully integrated onboard architecture.

Figure 21 NJ TRANSIT Bus Management Information System Onboard Architecture



8.2.2 State of the Art

Onboard system integration is not new. What is unique to state-of-the-art onboard bus integration, however, is the degree of cooperative interoperability and multi vendor interchangeability provided by a well and fully standardized onboard network architecture.

State-of-the-art onboard bus integration is distinguished by such features as:

Multi vendor interchangeability of vehicle location systems, vehicle processors, fare card readers, passenger counters, voice annunciation, video recording, data terminal, passenger display, and destination sign components;

Single-point operator sign-on;
Single sources for providing vehicle location, odometer, vehicle identification (ID), current time, block, route, run, and trip information, the data from which are shared via the onboard network by all onboard systems that need them;
Automatic acquisition of vehicle ID by newly installed data terminals, event recorders, and vehicle processors;
Odometer, time and location-tagged arrival, departure, passenger count, fare transaction, wheelchair lift, and video event records for each stop;
Odometer, time and location-tagged powertrain alarm, and vehicle health monitoring event records;
Conditional control of signal priority requests; and
System initialization and exception event records tagged with component serial number and software version ID.

Some level of operational integration is now the norm, where at least some of the installed systems routinely share information with one another in near real time over a standard onboard network. Integration to provide a single point of administration for these systems (e.g., updating internal software, files, and tables), however, has not yet been accomplished.

System administration often involves the transfer of files that are simply too large to transmit efficiently across a SAE J1708 network without disrupting the integrated operation of the onboard systems. Currently, which may be sufficient for most agencies, the state-of-the-art for system administration consists of individual wireless network connections to each installed system (or occasionally to each group of systems if purchased from the same vendor) from a common wireless LAN (Local Area Network) access point located at the base facility. These multiple links provide automatic updates of operating software sign files, schedules, map data, fare tables and voice annunciator files, and automatic download of event recorder data and digital video images — each over its own dedicated wireless LAN connection to the shared garage access point.

Examples of state-of-the-art onboard bus integration deployments found in transit include:

Centro, Syracuse, NY
Integration across vehicle location, passenger counting, data terminal, fare payment, and vehicle health monitoring systems[146]
Some issues regarding fare collection[147]

[146] Assessment of ITS Deployments, Technology Solution Providers, FTA DTFT60-03-00012, Arlington, TX, 2005, Table 4.
[147] Ibid.

185 equipped vehicles[148]

GC-RTA, Cleveland, OH
Integration across vehicle location, passenger counting, data terminal, fare payment, voice annunciation, and vehicle health monitoring systems[149]
Some issues regarding voice annunciation[150]
675 equipped vehicles[151]

LACMTA, Los Angeles, CA
Integration across vehicle location, passenger counting, data terminal, fare collection, destination sign, video recording, voice annunciation, and vehicle health monitoring systems with single-point operator sign on[152]
2,400 equipped vehicles[153]

8.2.3 Emerging Trends

The inability of the most common onboard operating networks to efficiently support the system administration function, together with the perceived "inelegance" of a collection of apparently redundant onboard wireless LAN transceivers, inexpensive as they may be, has prompted at least one major agency IT department[154] to suggest another approach. It involves the eventual migration of onboard systems and software away from application-specific onboard networks and industrial grade operating systems, like SAE J1708 and Unix or Linux, in favor of the conventional IT standards and PC operating systems with which they are typically more familiar such as Ethernet, XML, and Microsoft Windows. Whether full migration to a PC-based operating model would be actually feasible or desirable has yet to be fully investigated, but eventual migration to at least an IT-supported high speed Ethernet-based onboard network does appear probable.

[148] Intelligent Transportation Systems Deployment Statistics, US Department of Transportation, ITS Joint Program Office, Washington, DC, 2004, http://itsdeployment2.ed.ornl.gov/its2004/AdminViewSurvey.asp?SSN=TMandAgencyID=1756.
[149] Assessment of ITS Deployments, Technology Solution Providers, FTA DTFT60-03-00012, 2005, Table 4.
[150] ibid.
[151] Intelligent Transportation Systems Deployment Statistics, US Department of Transportation, ITS Joint Program Office, Washington, DC, 2004, http://itsdeployment2.ed.ornl.gov/its2004/AdminViewSurvey.asp?SSN=TMandAgencyID=409.
[152] APTS State of the Art Update 2005 web survey, Palisades Consulting Group, 2005.
[153] ibid.
[154] On-Board Digital Video Recording specification, New Jersey Transit Corporation, 2005.

8.3 Advanced Vehicle Safety Systems

8.3.1 Technology Description

Advanced Vehicle Safety Systems form the core of IVS. They include:

- Road departure warning systems;
- Lane departure warning systems;
- Rollover warning systems;
- Roll stability control systems;
- Obstacle detection systems;
- Collision warning systems;
- Collision avoidance systems;
- Collision notification systems;
- Driver alertness monitoring systems;
- In-vehicle vision enhancement systems; and
- Pre-crash restraint deployment systems.

Road departure warning systems use machine vision and other in-vehicle sensors to detect and alert drivers of potentially unsafe lane-keeping practices and to help keep drowsy drivers from running off the road.[155] Status: Under development.

Lane departure warning systems use technologies such as machine vision, magnetic strips, and GPS coupled with precise digital maps to warn drivers that their vehicle is unintentionally drifting out of the lane.[156] Status: Commercially available on automobiles.

Rollover warning systems use an onboard map database, GPS, other onboard sensors and, in some cases, short-range communications, to detect and notify drivers when they are traveling too fast for an approaching curve given current roadway conditions and the vehicle's current operating characteristics.[157] Status: Tested in over-the-road trucks.

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[155] Intelligent Transportation Systems Technology Overview, U.S. Department of Transportation, ITS Joint Program Office, Washington, DC, 2005. http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=CWS&SubSystem=RDW&Tech=Road.

[156] Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=CWSandSubSystem=LDWandTech=Lane.

[157] Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=CWSandSubSystem=RWandTech=Rollover.

Roll stability control systems take corrective action, such as automatically applying the brakes, when sensors detect that a vehicle is in a potential rollover situation.[158] Status: Under development.

Rear-impact warning systems attempt to prevent accidents by using radar detection to activate warning signs on the rear of the vehicle to warn tailgating drivers of impending danger.[159] Status: Under development.

Obstacle detection systems use vehicle-mounted sensors that include microwave RADAR or machine vision to detect obstructions such as other vehicles, road debris, or animals in a vehicle's path and then alert the driver.[160] Status: Under development.

Lane-change warning systems are a type of collision warning system that use microwave RADAR or machine vision to alert bus operators to the presence of vehicles or obstructions in an adjacent lane when the driver prepares to change lanes.[161] Status: Commercially available in automobiles, buses, and over-the-road trucks.

Intersection collision warning systems are a type of collision warning system that use machine vision, GPS, and dedicated short-range communications to detect and warn drivers of approaching traffic at high-speed intersections.[162] Status: Under development.

Forward collision warning systems are a type of collision warning system that use onboard sensors such as microwave RADAR and machine vision to help detect and avert vehicle collisions. These systems typically use in-vehicle displays or audible alerts to warn drivers of unsafe following distances. If a driver does not properly apply brakes in a critical situation, some systems take control and decelerate the engine or

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158 Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=DASandSubSystem=RSCandTech=Roll.

159 Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=CWSandSubSystem=RIWandTech=Rear.

160 Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=CWSandSubSystem=ODandTech=Obstacle.

161 Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=CWSandSubSystem=LCandTech=Lane.

162 Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=CWSandSubSystem=ICWandTech=Intersection.

apply brakes automatically in an attempt to avoid a collision.[163] Status: Tested in automobiles.

Advanced collision notification systems use in-vehicle crash sensors, GPS technology, and wireless communications systems to supply public/private call centers with crash location information, severity of the accident, and number of passengers on board (as determined from automatic passenger count data).[164] Such systems may also automatically transmit video images of the crash scene if vehicles are so equipped. Status: Commercially available in automobiles, buses, and over-the-road trucks.

Driver alertness warning systems use steering sensors to detect operator behavior indicative of fatigue or impairment, and then alert the operator and supervisory personnel of an apparent impaired condition to help prevent an unintended lane or roadway departure.[165] Status: Tested in over-the-road trucks.

In-vehicle vision enhancement systems use "heads up" see-through displays positioned directly in front of the driver's line of sight, along with forward-looking infrared technologies, to improve visibility for driving conditions involving reduced sight distance due to night driving, inadequate lighting, fog, drifting snow, or other inclement weather conditions.[166] Status: Commercially available in automobiles and over-the-road trucks.

Pre-crash restraint deployment systems[167] utilize the output of collision-warning devices to initiate just-in-time airbag deployment and tensioning of driver restraints to protect the vehicle operator and passengers in the event of a serious collision. Status: Tested in automobiles.

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[163] Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=CWSandSubSystem=FCWandTech=Forward.

[164] Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=CNSandSubSystem=AAandTech=Advanced.

[165] Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=DASandSubSystem=DDWSandTech=Drowsy.

[166] Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=DASandSubSystem=VEandTech=Vision.

[167] National ITS Architecture, Pre-Crash Restraint Deployment User Service, US Department of Transportation, Washington, DC, 2005. www.iteris.com/itsarch/html/user/usr66.htm.

Advanced Vehicle Safety Systems for public transit are not yet widely deployed in the United States. Only one of the 26 agencies responding to the 2005 State of the Art survey reported that any of these technologies had reached operational status at their agency.

8.3.2 State of the Art

While an extensive variety of vision enhancement, collision detection, and lane keeping devices are routinely being installed in many new over-the-road trucks, this technology has not yet been deployed in public transit in the U.S. With the notable exception of a variety of simple but effective front, side, and rear-obstacle detection systems, the current state of the art in advanced vehicle safety systems for U.S. public transit has only reached the demonstration stage. No intersection collision warning, rollover warning, roll stability control, lane departure warning, collision notification, vision enhancement, or pre-crash restraint deployment systems are reported to have reached actual fleet deployment in any public transit applications in the U.S.

The current state of the art in Advanced Vehicle Safety Systems deployments for public transit is typified by the Utah Transit Authority, which has deployed a factory-installed side collision warning system on about half of its 30 recently purchased small buses. The agency believes that one of the more cost-effective uses of such a system may be for training new bus operators rather than full fleet deployment.

8.3.3 Emerging Trends

Driver alertness warnings, collision notification systems, and in-vehicle vision enhancement systems are all commercially available for over-the-road trucks, and appear to be sufficiently proven to allow immediate implementation in public transit. In fact, vision enhancement systems have been available as factory-installed options in private automobiles since 2004. All that remains is for prospective commuter operators to specify them in upcoming procurements.

8.4 Vehicle Guidance/Automation

8.4.1 Technology Description

Vehicle Guidance/Automation systems are intended to help transit operators link multiple buses or light rail cars into close-coupled convoys (i.e. trains) and assist drivers with routine tasks to reduce driver workload.[168]

Vehicle Guidance/Automation technologies include:

[168] Intelligent Transportation Systems Technology Overview, http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=DASandSubSystem=ICCandTech=Intelligent.

Navigation and route guidance systems;
Precision docking systems;
Adaptive cruise control systems;
Coupling/decoupling systems; and
Lane keeping assistance systems.

In-vehicle navigation and route guidance systems use GPS technology to reduce driver error, increase safety, and save time by improving driver decision making in unfamiliar areas.[169] Status: Commercially available in automobiles, buses, passenger ferries, and over-the-road trucks.

Precision docking systems use machine vision, microwave RADAR, communications-based train control, or magnetic tags or strips to automate precise positioning (both longitudinal and lateral positioning) of vehicles at loading/unloading areas.[170] Status: Commercially available in buses, people movers, and heavy rail (rapid transit). Under development for passenger ferries.

Adaptive cruise control systems use microwave RADAR or laser ranging and electronic throttle and braking actuators to maintain safe following distance between platooned vehicles at any speed. Status: Commercially available in automobiles and over-the-road trucks.

Coupling/decoupling systems extend the concept of adaptive cruise control to support close-coupled vehicle operations, where vehicles follow one another at extremely close distances, usually in an exclusive lane. These systems use machine vision, microwave RADAR, short-range wireless communications, and electronic actuators to provide precise automated vehicle control in high speed Bus Rapid Transit operations. Status: Under development.

Lane keeping assistance systems are the logical extension of a lane departure warning system, using electronic actuators to make minor steering corrections if the vehicle detects an imminent lane departure without the driver using a turn signal.[171] As currently demonstrated, such systems are designed to apply only limited torque

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[169] Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=DASandSubSystem=NandTech=Navigation.
[170] Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=DASandSubSystem=PDandTech=Precision.
[171] Op. cit., http://itsdeployment2.ed.ornl.gov/technology_overview/Options.asp?System=DASandSubSystem=LKAandTech=Lane.

(approximately two foot-pounds as measured at the steering wheel) so that they can be easily overridden by the vehicle operator.[172] Variations of the lane keeping assistance concept that mechanically track the curb or a rail imbedded in the roadway also exist. Status: Demonstrated in buses and over-the-road trucks. Under development for passenger ferries.

Vehicle Guidance/Automation technologies are not yet widely deployed in the United States. Only one of the 26 agencies responding to the 2005 State of the Art survey reported that any of these technologies had reached operational status at their agency. However, mechanical lane keeping systems have been successfully deployed for both short distance (1,000 ft) traffic signal queue bypass lanes and medium distance (7 miles) bus rapid transit lanes in England, other parts of Europe, and Australia.

8.4.2 State of the Art

Navigation and route guidance systems are relatively common in recent state-of-the-art vehicle procurements, but the only public transit vehicle guidance/automation application reported to have reached actual deployment status in the United States is a precision docking application in Las Vegas, Nevada. Although commercial applications do exist in Europe, Asia, and Australia, the current state of the art in U.S. vehicle guidance/automation is limited to precision docking. No adaptive cruise control, coupling/decoupling, or lane keeping assistance systems are reported to have been actually deployed on transit vehicles in the United States.

Surprisingly, the current state of the art in cost-effective vehicle guidance/automation applications does not even include an advanced technology component. Though not sufficient for all bus rapid transit applications, these mechanical lane keeping systems utilize horizontal rubber guide wheels linked to the steering mechanism to maintain precise positioning to within one inch at highway speed. They cost about $2,500 per bus and $2M per new lane mile to install. Lane-keeping systems allow buses to join and leave the assisted roadway at highway speeds and, because they can be implemented in short segments at targeted intersections at relatively little expense, are especially well suited to the task of cost-effectively allowing buses to bypass automobile queues at speed using narrow guideways on the shoulder or median at critical arterial intersections.[173]

Examples of state-of-the-art deployment of Vehicle Guidance/Automation deployments found in transit include:

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[172] Multimodal Vehicle Assist and Automation; VAA Systems for Transit Operations, Hardy and Proper, Mitretec Systems, Washington, DC, 2005.

[173] Bus Rapid Transit Lane Assist Technology Systems, Metro Transit and University of Minnesota, Minneapolis, MN, 2003, p. 23. www.its.umn.edu/research/applications/brt/laneassist/LAfinal1.pdf.

Regional Transportation Commission of Southern Nevada

- Automated self-docking of ten 60-foot Bus Rapid Transit vehicles to level boarding platforms
- Machine vision technology using roof-mounted cameras to detect white painted lines on the roadway surface
- Reliable positioning with 3” tolerance between vehicle and boarding platform
- Ten equipped buses
- 15 stops

Adelaide Metro (Australia)

- Mechanical lane keeping assistance system
- One inch position tolerance
- Seven miles of dedicated bus transit guideway operated on 20-second headways at 60 MPH
- 30,000 passengers per day

8.4.3 Emerging Trends

Recent demonstrations indicate that electronic lane keeping assistance systems can be used to allow a 102-inch wide bus to safely operate in a 114-inch-wide lane or shoulder in good conditions,[174] but operation in snow or icy conditions has not yet been investigated in sufficient depth to allow deployment in central or northern regions of the country.[175]

8.5 Intelligent Rail Vehicle Integration

8.5.1 Technology Description

Like Intelligent Onboard Bus Integration, Intelligent Rail Vehicle Integration provides the means by which the various discrete subsystems found on a railcar can be made to interoperate to maximize the functionality, reliability, usability, efficiency, and effectiveness of the transit system, while minimizing total life cycle cost. The one critical element that distinguishes rail integration from bus integration is that rail integration not only links the discrete subsystems on a given vehicle, but also the many vehicles (railcars and locomotives) of a given train as well.

Because of the need to periodically couple and decouple trains of individual cars and locomotives of different generations, rail integration is somewhat more complicated than bus integration. The key to rail system integration is the “trainline.” A

[174] Ibid.

[175] Hardy and Proper, op. cit.

conventional trainline is a multi conductor cable that runs the entire length of the train, which in some cases can be a third of a mile or more. Long before digital network technology was developed, rail operators in the U.S. decided to implement a 27-conductor trainline — 27 discrete wires of various sizes for electrical power, door control, propulsion and braking control, and public address — with a standardized 27-pin jumper to propagate the trainline between each car and locomotive.

To achieve intelligent rail vehicle integration, the conventional 27-conductor trainline and 27-pin jumper are supplemented by a high-speed digital network. Interface components within the cars and locomotives can be configured such that an equipped car can automatically communicate with adjacent cars via the network, the 27-pin jumper, or both, thereby allowing for mixed consists of new and old cars to interoperate together, and providing a migration path for eventual discontinuation of the conventional discrete wired trainline.

The potential cost savings to be gained through use of this advanced trainline network are significant. Using the network, locomotive engineers operating from a cab car at the far end of the train can receive the complete range of equipment status and diagnostic information available in the locomotive cab. Train consists, which previously required individual cars to be oriented in the same direction (i.e., "A" end to "B" end) for the crew to open doors only on the platform side of the train, for example, can now be coupled indiscriminately in any orientation because the network on each car can adapt to whatever orientation it determines itself to be in.

Because of the greater cable distances involved, both within an 87-foot long railcar and along a 1,200-foot-long commuter train, rail networks tend to be built on different network technologies from their bus counterparts. Currently, the most commonly used network technology for state-of-the-art intelligent rail vehicle integration is that built on the Institute of Electrical and Electronics Engineers (IEEE) standard 1473 for communications protocols aboard trains. IEEE 1473 specifies a family of three complementary network technologies for communications along the length of the train and within the car. Two of these require their own independent network cabling, while the third is capable of operating over the same cables that provide the high-voltage electrical power to the train.

All of the recent major railcar procurements in the U.S. have included some degree of rail system integration across a standard network. Most common is integration between the locomotive and the remote operating console in a cab car (to provide the full range of locomotive alarms and diagnostics in either location), between the door control system, the throttle, and the antilock braking system (to prevent inadvertent train movement while boarding or discharging passengers), and between passenger information signs throughout the train.

8.5.2 State of the Art

Led by the Association of American Railroads (AAR), the U.S. rail industry has long enjoyed a level of multi vendor interchangeability of radio systems, event recorders, mechanical components, and other such items that is virtually nonexistent with buses. What is unique to state-of-the-art rail vehicle integration, however, is that this advanced level of multi vendor interchangeability has now been extended to the car-borne control and information systems as well, allowing the various onboard systems to deliver a much higher level of cooperation and interoperability than ever before.

State-of-the-art rail vehicle integration is distinguished by such features as:

- Multi vendor interchangeability of vehicle location systems, vehicle processors, passenger counters, voice annunciation, video recording, data terminal, passenger display, and destination sign components;
- Automatic consist identification and car orientation determination;
- Support for mixed-mode trainline operation (digital network versus 27-pin);
- Single-point operator sign-on;
- Intelligent load shedding;
- Full range of locomotive status and diagnostics information available at both locomotive and cab car;
- Single point of maintenance data access for all systems on a given car;
- Single point of maintenance data access for all cars throughout the train;
- Single point of file update and administration for passenger information, destination signs, and voice annunciators throughout the train;
- Passenger load distribution information available to both engineer and crew;
- Single sources for providing vehicle location, odometer, vehicle identification (ID), current time, route, and trip information shared by all onboard systems on the network;
- Passenger information displays synchronized throughout the train;
- Stop announcements that adapt to current location and operating condition, announcing destination and intermediate stops while boarding passengers, and providing "next stop" information between stations;
- Variable door control timing that keeps automatic vestibule doors open longer when stopped and boarding passengers;
- Automatic logging of cut out or bypassed components and features;
- Odometer, time and location-tagged arrival, departure, passenger count, and video event records for each stop;
- Odometer, time and location-tagged propulsion and braking alarm, and vehicle health monitoring event records; and

System initialization and exception event records tagged with component serial number and software version ID.

Examples of state-of-the-art Intelligent Rail Vehicle Integration deployments found in transit include:

New Jersey Transit, Newark, NJ
- IEEE 1473 trainline network
- Fully networked door control
- 300 railcars equipped
- Mixed mode trainline operation

MTA New York City Transit, New York City, NY
- IEEE 1473 trainline network on all new subway cars

8.5.3 Emerging Trends

The IEEE Rail Transit Vehicle Interface Standards Committee (RTVISC) is working to define the data and messages required to standardize the administration of sign and voice annunciator systems. This work is nearly complete. With manufacturers' costs for nonrecurring engineering borne by early implementers, and network technology now routinely built into new railcars and locomotives, prices for advanced rail vehicle integration have fallen to the point where even the smallest rail operators can take advantage of the new technology.

8.6 Challenges and Lessons Learned

8.6.1 Use of Standards

There are two subtle issues that apply even to "standardized" message profiles like SAE J1587 that agencies with state-of-the-art applications have learned through experience to avoid. They include "local use codes" and use of the "data link escape." In the case of local use codes, most standards provide for the use of locally defined codes for cases where the standard codes are deemed inadequate or inappropriate. Standards also provide a "data link escape" for nonstandard file transfer. Use of locally defined codes and the data link escape in place of standard codes is one method that some vendors have employed to allow them to be technically in compliance with the standard, while still continuing the deployment of devices with proprietary interfaces that can only interoperate with other devices obtained from the same vendor.

The practice by some vendors to deploy devices with proprietary interfaces is made possible because the process to request an enhancement to a standard is relatively straightforward and easy to achieve. Commonly used interface standards are maintained by organizations responsible for processing requests for updates and revisions of the standards, and vendors can typically get a revision balloted and approved in 6-9 months. As a result, agencies have learned to build careful controls on the use of locally defined codes and the data link escape into their procurement specifications for onboard systems and components to avoid unintentionally proprietary interfaces.

8.6.2 Avoiding Sub-optimized Implementations

Onboard system integration promises significant benefits to transit and the riding public at relatively little cost. However, when supporting infrastructures such as onboard networks, vehicle processors, wireless communications, and corporate databases are implemented only to support the limited functionality specified by an individual business unit to fill an individual business need, these technologies begin to appear far less cost-effective than they could be. For example, state-of-the-art agencies have found that while an AVL or video recording system might cost $10,000 per vehicle, the addition of APC, equipment health monitoring, event recording, electronic defect reporting, voice annunciation, and single-point operator sign-on may only cost a few thousand dollars more. Moreover, if considered in the design stage, these additional features can easily make use of the same wireless communications and database infrastructures that are also required for the initial application.

8.6.3 Vehicle Networks

Agencies that have installed vehicle networks onboard buses and/or trains have found them easy to design and implement. They have also discovered that installation is best accomplished during vehicle assembly, rather than as a retrofit, and that use of standardized cables and connectors can greatly simplify subsequent component installation.

Although the networks work well, agencies find that the resultant integration of systems on the networks do not always operate as intended. One pitfall common to many of the early system integration efforts across a vehicle network involved vendors trying to implement component applications without adequate testing of the various failure modes unique to network communications. This was especially the case with trains, where network messages must be propagated across multiple individual vehicles. This lack of adequate testing often occurs when agencies procure their vehicles with a technical specification rather than a performance specification, thereby forcing them to assume much, if not all, of the risk if the technical specification should prove inadequate. Inadequate testing also occurs when only a few months are allocated for it.

In essence, state-of-the-art agencies have learned to shy away from specifying technical details and "approving" vendor designs. Instead, they have sought out the training needed to move beyond technical and even functional specifications (i.e., how the system operates or what the system does) in favor of performance and behavioral specifications (i.e., defining what the system needs to accomplish and how the system is to function under various conditions). Agencies have learned to specify an integrated concept of operations where "the system" is not any one component, but represents the totality of the various components and subsystems involved in the overall vehicle integration effort.

Agencies with state-of-the-art deployments have also learned to specify the minimum modularity required of the vehicle architecture, and make certain that they retain unrestricted rights to every interface into and out of every component on the vehicle to assure multi vendor interchangeability and ease of system administration and upgrade ability throughout the network.

Finally, agencies have learned to conduct prototype testing for prolonged periods of six months or more, and to base final acceptance on the original performance specification. Testing is required for each and every specified requirement, rather than discrete subsystem tests based on convenient pieces of the vendor's subsequent functional or design specifications. Agencies have also learned to take delivery of at least one complete bench test vehicle emulator for their own use in troubleshooting equipment failures after deployment.

8.6.4 System Administration

Operational integration is only part of state-of-the-art system integration. It also includes wireless system administration, providing the ability to remotely update destination sign, schedule and annunciator files, fare tables, and software without ever visiting the vehicle. Wireless administration promises real reductions in operating and maintenance costs for intelligent vehicle systems. Savings can amount to $15 per application, per vehicle, per quarter, or $3,600 per vehicle over a 15-year life on a vehicle equipped with fare collection, stop annunciation, destination signs, and AVL. However, vehicle-wide wireless administration is not yet a reality. Some agencies have implemented wireless administration for some onboard systems, but none have yet completely eliminated the need to physically visit the vehicle for routine system administration and troubleshooting.

8.6.5 Intelligent System Integration

Transit agencies and vendors alike are breaking new ground as they strive to compress data entry and display for multiple applications into fewer and fewer discrete user interface devices.

For noncritical system integration, where the vehicle operators can take the time to look down and choose between the various inputs available to them, a user interface with a hierarchical "chapter and page" organization appears to work well enough. These hierarchical user interfaces are often supplemented with a global system status page providing an integrated presentation of the health and status of the various vehicle systems.

For safety-critical integration, there is a need to provide real-time input to the vehicle operator that is invariably clear, correct, and complete. However, additional research and experimentation will be required before an optimal real-time user interface can emerge. The same holds true with regard to integration between vision enhancement, lane keeping, and collision avoidance.

8.6.6 Advanced Vehicle Safety Systems

While some advanced vehicle safety systems can be deployed with little user interaction (e.g., pre-crash restraint deployment), most AVSS applications will require extensive work toward user acceptance. For example, vehicle operators must be able to understand and trust the output of these systems.

Early researchers have concluded that, especially with respect to collision warning and avoidance systems, the integration of various separate warning systems into a user interface that presents a clear and unambiguous message to a (possibly stressed) vehicle operator will be a critical element of gaining this acceptance.[176] Additionally, although outside the purview of this state-of-the-art discussion, it should be noted that as with any safety-related item, the real issues may be institutional rather than technical. Liability issues can be expected to play a determining role in AVSS deployment.

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Appendix A Press Release Dated May 23, 2005

FTA ITS REPORT SEEKS INFORMATION ON STATE-OF-THE-ART OF TRANSIT ITS FROM TRANSIT AGENCIES AND VENDORS

May 23, 2005 — The Federal Transit Administration (FTA) is preparing its seventh in a series of Intelligent Transportation Systems (ITS) State of the Art (SOA) reports for 2005. Information contained in these reports highlights the very best transit ITS deployments (also known as Advanced Public Transportation Systems, or "APTS") and serves as a useful communication tool to inform the industry of this increasingly complex subject.

In addition to highlighting successful ITS applications, FTA's SOA Report will provide a description and overview of each major ITS technology, highlight the lessons learned by agencies with successful implementations, and present the issues and hurdles surrounding ITS deployments. The SOA 2005 report will also include a stronger focus on many of the important but often overlooked support systems and business processes needed to successfully implement ITS technologies. All of the major public surface transportation modes will be addressed, including bus, rail, ferry, and intermodal service operations.

The FTA Intelligent Transportation Systems Office has contracted with the Palisades Consulting Group, Inc. of Tenafly, New Jersey, to prepare its next SOA report. As part of its search for SOA information, Palisades is asking transit agencies and vendors with successful ITS implementations to complete a simple, online form: www.palisadesgroup.com/StateOfTheArtQuestionnaire.htm. The cutoff time and date for submitting the surveys is **5 pm, EDT on June 15, 2005.** A Palisades representative will follow up with additional questions if needed.

Topics where information is requested include:

- **ITS Integration**, including transit ITS standards and architecture, geographic information systems (GIS), and enterprise data;
- **Fleet Management**, including communication systems (i.e., radio, AVL, etc.), service planning support systems, transit signal priority, and transportation operations systems;
- **Electronic Fare Payment**, including fare system, fare payment products, and clearinghouse/regional service centers;
- **Traveler Information**, including pre-trip information systems, in-terminal/wayside systems, in-vehicle systems, multimodal systems, and transit trip information infrastructure;
- **Transit Safety and Security**, including vehicle, facility, and station security, incident response, and incident planning and management systems;
- **Transportation Demand Management**, including dynamic ridesharing, automated service coordination, and multimodal transportation management centers; and
- **Intelligent Vehicle Systems**, including onboard bus integrations, Intelligent Vehicle Initiative, and intelligent rail vehicle.

For additional information about the project, contact Eva Lerner-Lam, Palisades Team Project Director, at 201-567-0088, ext. 11 or elernerlam@palisadesgroup.com.

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Appendix B State of the Art Update Survey

Transit ITS (APTS)
State of the Art Update Survey

Are you on the cutting edge of Advanced Public Transportation Systems (APTS) technology? Is some aspect of your system smarter, faster, cheaper, more capable or easier to use than anyone else's? Is it more reliable? More maintainable? Is there something you've done institutionally that allows you to reap greater benefits from the system than most others might?

Please take a few minutes to help your peers throughout the transit industry by identifying state-of-the-art APTS applications for inclusion in the next edition of FTA's Advanced Public Transportation Systems (APTS) State of the Art report.

Organization Name:

Website Address:

E-mail Address:

In which areas have you deployed what you believe to be truly innovative APTS applications? (please check all that apply):

System/Data Integration

- ☐ Wireless Communications
- ☐ Transit ITS Architecture (open systems integration)
- ☐ Transit ITS Standards
- ☐ Geographic Information Systems (GIS)
- ☐ Enterprise Data Management

What makes these systems different from what's been done before?

Fleet Management

- ☐ Service Planning Support Systems (e.g., APC)
- ☐ Transit Signal Priority
- ☐ Maintenance Management Systems
- ☐ Computer Aided Dispatch (bus, rail, ferry, paratransit, etc.)

What makes these systems different from what's been done before?

Traveler Information

- ☐ Transit Information Systems (pre-trip, enroute, onboard, at stop, personalized, etc.)
- ☐ Multimodal Travel Information
- ☐ Transit Information Infrastructure (architecture, data sets, trip planning engines, etc.)

What makes these systems different from what's been done before?

Transit Safety and Security

- ☐ Onboard Security
- ☐ Station/Facility Security
- ☐ Incident Response
- ☐ Disaster and Incident Management Planning Support Systems

What makes these systems different from what's been done before?

Transportation Demand Management

- [ ] Dynamic Ridesharing
- [ ] Automated Service Coordination
- [ ] Multimodal Transportation Management
(parking management, modal demand management, etc.)

What makes these systems different from what's been done before?

Intelligent Vehicle Systems

- [ ] Intelligent Onboard Integration (bus, rail, etc.)
- [ ] Advanced Vehicle Safety Systems
- [ ] Vehicle Guidance/Automation

What makes these systems different from what's been done before?

Other (please specify)

-
-
-

Were especially innovative management and/or procurement methods critical to successful implementation of any of the applications noted above?

- Yes
- No

If yes, please explain

What are some of the most interesting APTS applications you have seen? Why? At which agencies?

Do you collect Return on Investment (ROI) data on any of your advanced systems?

☐ Yes

☐ No

	Recommended Contact Names	Telephone	Project Name
1.			
2.			
3.			

Mailing Address	
City	
State	
Zip	
Country	

Reset Submit

Thank you for your input and your time.

Questions about the State of the Art update report? Write us at Survey@palisadesgroup.com.

Appendix C Information Technology (IT) Local Area/Wide Area Networking Strategies

IT Network Architecture Table		
Transitional	**State-of-the-Art**	**Emerging**
OSI Layer 1 - Physical		
Coaxial cabling, Category 3 unshielded twisted pair (UTP), shielded twisted pair (STP), and 62.5/125-micron multimode fiber.	Category 5e UTP (supersedes Category 5 UTP), 50/125-micron multimode fiber, 6/125-micron single-mode fiber. Logical star topology, SONET, ISDN/PRI, xDSL, cable modem protocols	Category 6 UTP, wireless. Logical meshed star topology
OSI Layer 2 – Data Link		
Single-segment LANs, separate dedicated networks for different services (e.g., voice and data), separate dedicated networks for various user groups, proprietary protocols (DECnet), FDDI, X.25, time-domain (channelized) protocols (e.g., SDLC, HDLC).	Open-standards-based, multiservice networks; 100/1000 Ethernet; 802.11 LAN, 802.16 MAN Wireless Ethernet; Frame Relay; ATM.	Packet- and cell-based wireless, dynamic data-link level switching, and prioritization, 10G/40G Ethernet.
OSI Layer 3 – Network		
Separate dedicated networks for different services (e.g., voice and data), flat designs with unmanaged bridges, hubs, proprietary protocols (e.g., IPX, and DECnet).	Converged networks with prioritization for all services; switched, multisegment design; IP; RIP; BGP; OSPF; IP switching; and DHCP.	Dynamic, network-level switching and prioritization. VoIP, H.323
OSI Layer 4 – Transport		
Fixed IP addressing and proprietary protocols, e.g., SPX	Converged networks with prioritization for all services, TCP, and UDP.	IPv6 and dynamic transport-level switching and prioritization.
OSI Layer 5 – Session		
	DNS	Dynamic, session-level switching and prioritization.
OSI Layers 6 and 7 –Presentation and Application		
	SNMP; RMON; SMTP.	Dynamic, content-level switching and prioritization.

Appendix D Fleet Management Example of a Performance-Based Specification Template

Below is a sample specification template that illustrates key features of a performance-based approach to procurement of a fleet management system.

Note: As might be expected, because this recommended outline is for "performance-based" specifications rather than the traditional "design" specification, it deviates significantly from the sample 6-section design specification format provided in the FTA Best Practices Procurement Manual.

- **Project objective**. Example: To construct and implement a new transit management center and statewide radio infrastructure, and to deploy an expandable, maintainable, automated system for planning, managing, and controlling bus, paratransit, ferry, and passenger information operations and maintenance throughout the *(agency)* service area on ___ buses, ___ paratransit vehicles, ___ passenger ferries, and ___ nonrevenue vehicles operated out of ___ vehicle base facilities…
- **Project scope**. Example: The contractor shall provide all tools, equipment, materials, software, and services required to achieve the project objective, per these specifications, with the exception of …, which will be provided by *(agency)* or others, together with five years of comprehensive unlimited warranty support for installed hardware and five years of software maintenance support.
- Critical mission requirements (basic acceptance criteria) with separate specifications for as many distinct operational environments as may exist. Example:

    The system shall allow authorized personnel to… *(do whatever, in whatever situations, with whatever levels of effort, accuracy, and performance that the agency requires)*;

    The system shall provide to passengers with telephone access at any and all bus stops following information: "next bus to ______ will arrive in ___ minutes" accurate to within: a) 5 minutes in greater than 99 percent of all cases, and b) 3 minutes in greater than 95 percent of all cases;

    The system shall provide a means for vehicle operators to initiate communications with the control center with a single action;

    The system shall allow authorized users to view and report response times and lost call rates for all communications;

    The system shall allow control center personnel to respond to priority requests to talk within 15 seconds of the operator's initiation of the request in greater than 99.98 percent of all cases;

The system shall automatically report failure of any system component within 12 hours of failure occurrence;

The system shall continue to provide required functional performance during periods of power failure, single equipment failure…;

… and many more, as required.

- Additional desired features/characteristics with anticipated annual value to the agency for each. Note: Stating the anticipated value of each additional desired feature up front helps prevent casual items from driving up project cost, allows vendors to develop more responsive proposals, and sets the stage for collaborative value engineering prior to issuance of the final amended RFP to short-listed firms.
- Concept of operations (i.e., use-case scenarios, expected sequence of events, and degree of manual intervention required to carry out a given operation.) Example: Load a new schedule, locate a vehicle, degree of automation, etc.
- Nonfunctional requirements. Example: Scalability, overall system reliability, multi-vendor component availability, life cycle support for hardware and software maintenance, mean time between component failures, mean time to repair, etc.
- Design Constraints. Example: preferred operating system, preferred database management system, preferred communications provider, required third-party tools, user interface specifications, required modularity, architectural interfaces, interface standards, profiles, etc., with the anticipated annual value to be gained through each.
- Training and Documentation requirements. Note: The documentation should be tested for accuracy and completeness just as rigorously as the system itself.
- Acceptance test scenarios for system and associated documentation, identifying any special cases and boundary conditions that may be important to the agency. Example: Provide scenarios that the agency staff may consider to be difficult for a vendor's system to handle properly, either in general or in their specific operating environment. System performance should be tested against each and every affected mission requirement for each relevant test scenario.
- Service Delivery Specification items. Example: Specify payment milestones, project administration and reporting requirements, schedule of penalties, required maintenance response times, etc., as well as requirements for project management plans, design reviews, installation plans, etc. that are to be proposed by the vendor and finalized prior to contract award.
- Appendices (not part of the specification per se, but necessary to support the

procurement process).

Examples:

- Proposal requirements;
- Proposal evaluation criteria;
- Background; and supporting information.

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