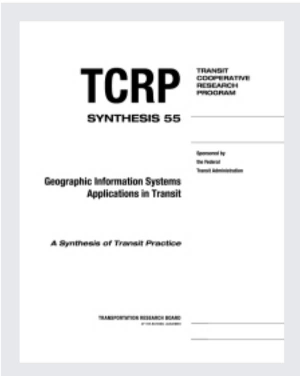

Geographic Information Systems Applications in Transit

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TCRP

TRANSIT
COOPERATIVE
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SYNTHESIS 55

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Transit Administration

Geographic Information Systems Applications in Transit

A Synthesis of Transit Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

TRANSIT COOPERATIVE HIGHWAY RESEARCH PROGRAM

TCRP SYNTHESIS 55

Geographic Information Systems Applications in Transit

A Synthesis of Transit Practice

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TRANSIT COOPERATIVE RESEARCH PROGRAM

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

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

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

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

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FOREWORD

By Staff
Transportation Research Board

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

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

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

PREFACE

This synthesis will be of interest to transit practitioners and researchers, including technical staff and transit managers, as well as to vendors of Geographic Information System (GIS) solutions. This report illustrates the value of GIS to transit agencies in service provision and in potential cost savings. The synthesis summarizes the experiences of a variety of transit agencies, with information provided from small- and medium-sized transit operators, as well as from large transit agencies. It documents current practices, effective applications, and challenges.

This report from the Transportation Research Board includes a broad-based literature review supplemented by survey responses from more than 100 transit agencies. The report covers the full range of transit services including planning, operations, management, information technology, and customer service. Included are case studies from five large transit operators that demonstrate a number of innovative uses of GIS, as well as illustrate how GIS is becoming a part of mainstream information technology and a core technology in transit information services.

A panel of experts in the subject area guided the work of organizing and evaluating the collected data and reviewed the final synthesis report. A consultant was engaged to collect and synthesize the information and to write the report. Both the consultant and the members of the oversight panel are acknowledged on the title page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

GEOGRAPHIC INFORMATION SYSTEMS APPLICATIONS IN TRANSIT

SUMMARY

Over the years, Geographic Information Systems (GIS) technology has been implemented for a variety of purposes within the transit industry. With this have come many new uses, benefits, and challenges. The purpose of this effort is to survey a variety of transit agencies to document current practices, effective applications, and challenges in GIS technology. This synthesis provides a state-of-the-practice review of the application of GIS in transit planning and operations. It will be of interest to transit practitioners and researchers including technical staff, transit managers, and vendors of GIS solutions. The synthesis illustrates the value of GIS to transit agencies in service provision and in potential cost savings.

The synthesis includes a broad-based literature review, supplemented by information from a survey of transit agencies and case studies of five large transit operators. It covers the full range of transit services including planning, operations, management, information technology, and customer service. The review of GIS technology includes the historical development of GIS and its business organization among transit agencies, which is broadly categorized at three levels of implementation: project-, department-, and enterprise-wide. Although agency size generally corresponds to these levels, size alone is not the only determinant of GIS deployment. Commitment from the agency toward the GIS program and its historical development within an agency also influence its development path. Beyond the agency, there are resources available to support GIS implementations from vendors, federal and local governments, and industry initiatives such as the intelligent transportation services. These are reviewed together with national initiatives in geospatial technologies and standards for transit information systems.

A literature review of GIS publications for transit provides examples of applications moving beyond the traditional areas of planning and information systems into planning, operations, management, information technology, and customer service. The review of the literature and technology demonstrates the variety of uses of GIS in transit. It is evident that this use is growing and that the technology is now mature enough to be considered a core technology in transit service delivery. There have been significant advances in GIS technology, in its user-friendliness and capabilities to link to non-GIS programs such as scheduling, trip itinerary planning, and automatic vehicle location (AVL). GIS thus enables these other technologies and can present the information to the public in a visual manner that they understand. The public is becoming more accustomed to on-line maps, and transit programs that do not include maps lack visual appeal.

Following the technology review is an analysis of the results of the 2002 and 2003 transit GIS survey conducted by the GeoGraphics Laboratory at Bridgewater State College, Bridgewater, Massachusetts. This web-based survey elicited more than 100 responses from mainly small-to-medium-sized agencies. The results show the growing use of GIS across a broad spectrum of application areas, including the traditional areas of building inventories of bus stops, routes and schedules, and in service planning and analysis, as well as newer appli-

cation areas such as AVL and trip itinerary planning systems. There is also a growing use of GIS in response to FTA policies and regulations, such as Americans with Disabilities Act compliance, Title VI programs, Welfare to Work programs, and paratransit services. The results also reveal a desire for more use of GIS in areas of security and police operations. There are currently few examples of this but it appears to be an area for future growth and development.

Because the 2002 and 2003 surveys are somewhat skewed toward small- and medium-sized transit agencies, it was decided to conduct detailed case studies of five large transit agencies. The case studies demonstrate a number of innovative uses of GIS as well as illustrate how GIS is becoming part of mainstream information technology and a core technology in transit information services. An example of this is the use of GIS and global positioning systems in AVL applications, which require the capture and display of real-time data. There are also some interesting projects that are interfacing GIS with other multimedia such as images and video technologies, both to record information on transit assets as well as in community participation exercises. Clearly, to engage in these more advanced projects requires resources and staff with special skills. Nevertheless, these applications indicate the direction of GIS integration. As the technology has evolved and become more user friendly, it is more widely available to users on their desktops or through the Internet. There is less need for GIS specialists to perform basic services such as map production or the answering of simple queries. Rather, they are engaged in more specialized tasks such as geodatabase management, applications development, and systems integration. The constituency of users of GIS in a typical large transit agency is now very broad and spread across multiple departments.

The synthesis highlights the range of GIS applications and draws some conclusions on the evolution of GIS through different stages of development within transit agencies. GIS implementation has its own requirements for data, human capital, tools, and applications. GIS is a technology with many benefits and adds value to transit planning and operations. It has proved to be a catalyst for the integration of transit business and geographic data, developed new types of applications that can take advantage of geographic data, and enhanced the information technology capabilities of transit agencies with new tools for visualization and dissemination of transit data to internal and external customers. These benefits are not always evident in transit programs and sometimes difficult to identify within the broader institutional setting. The challenge for GIS is how to justify investment in its growth and development beyond the traditional application areas. The case studies provide some examples of how this breakthrough is being accomplished and provide pointers to the future applications of GIS. Finally, the synthesis identifies some gaps in knowledge and information on transit GIS and makes some suggestions for further research.

CHAPTER ONE

INTRODUCTION

BACKGROUND

The use of Geographic Information Systems (GIS) in transit has been of interest to transit researchers and practitioners for at least a decade. There were some early attempts in 1992 and 1993 to record the level of use within transit agencies (FTA GIS surveys), and between 1995 and 1999 three national conferences were held on the theme of GIS in transit. These events showed that GIS use in transit is closely linked to the environment within which it is nurtured; that is, its history within the organization is an important factor in its present deployment. In the period since 1993, transportation has been one of the fastest growing areas of GIS deployment, although its rate of growth has slowed since 2001 as the technology has matured and become more widespread among transportation agencies. During this period the capabilities and user friendliness of GIS have changed considerably, such that the ability to use these tools is becoming broader based. There is less need to rely on specialists to derive value from the GIS. Simultaneously, transit agencies' approach to using GIS has become more scalable, from basic infrastructure projects to enterprise implementations. Whatever the stage of GIS development it still needs an underlying infrastructure of information technology (IT) and spatial data that requires regular maintenance.

Despite this level of interest and widespread use within the industry, there has not been a comprehensive review of the state of the practice. This synthesis provides an overview of the use of GIS in transit planning and operations. Some topics are covered in more detail than others where sufficient information exists to allow a detailed review. The focus is mainly on transit bus systems, which provide the majority of transit service in the United States; however, examples of commuter rail and metro rail uses of GIS are included where appropriate. This synthesis will contribute to the knowledge and understanding of GIS in transit and could encourage further research and development of these issues.

PROBLEM STATEMENT

Transit agencies need to provide efficient service to respond to customer demands and shifting land use. A GIS has the capacity to support operations, planning, management, and customer services that can lead to a more effective allocation of limited resources within transit agencies. For a GIS to become truly functional, an effective infrastructure consisting of data, people, and tools is needed. Despite the benefits of GIS in transit operations and planning, the use of GIS is not widespread, and even where GIS is installed it is often used for specific low-key applications rather than being fully integrated with the agency's information systems and business processes. As hinted previously, this may be because of the complexities and costs of setting-up and managing a GIS program or it could be because of institutional inertia to a new technology and concern of its impact on established business processes. Therefore, significant barriers to implementing GIS in transit agencies still exist. The synthesis will analyze these constraints and how they may limit GIS uptake; as a corollary, it will also evaluate some success stories and how the barriers were overcome.

SCOPE

Over the years, GIS technology has been implemented for a variety of purposes within the transit industry. With this have come many new uses, benefits, and challenges. The purpose of this effort is to survey a variety of transit agencies to document current practices, effective applications, and challenges. Some of the GIS issues addressed in this report are:

- Data—including data collection and maintenance; data integration with related spatial data sets, including scheduling, infrastructure, operations, and planning; and inter- and intra-agency data coordination and sharing.
- Human capital—including hiring, training, professional development, and organizational structures.
- Tools/applications—including:
  - Information technology, including hardware, software, and custom tools;
  - Operations, including vehicle and facility management, vehicle location, routing and scheduling, and real-time traffic information;
  - Planning, including route and facility planning, automated passenger counting (APC) systems, ridership reporting, demographic analysis, and modeling tools;
  - Management, including safety, security, and incident response; system performance and reporting; asset management; and finance; and

– Customer services, including trip itinerary planning, customer relations, real-time customer information, public information, and marketing.

APPROACH

This synthesis documents the state of the practice in applications of GIS technology. Using a review of relevant literature and a survey of selected transit agencies, it draws from a range of resources, as well as a number of case studies. The report identifies areas of common concerns, documents the value of GIS, and profiles innovative and successful practices, as well as lessons learned and gaps in information.

In addition to the survey, this synthesis relies substantially on in-depth case studies of some of the leading users of GIS together with a broader-based literature review of the state of the practice, including analysis of the results of GIS surveys among small- and medium-sized transit properties. The case studies allowed for a more detailed review of GIS applications, as well as evaluation of constraints in applying GIS technology, which would have been difficult to collect in a survey format. Five large transit properties were visited and discussions were conducted with the GIS staff and managers of the GIS programs. A large amount of information was collected and is synthesized in this report.

ORGANIZATION OF REPORT

Following this Introduction, chapter two provides a review of GIS services and practice in transit agencies. This includes a literature review of more than 130 publications, with some of these examples of how GIS is being used in practice. This chapter also includes a review of resources to support GIS deployment in transit agencies, such as GIS standards, intelligent transportation systems (ITS), and transit GIS research at universities. Chapter three summarizes the results of the GIS in transit surveys conducted by Bridgewater State College (Bridgewater, Massachusetts) in collaboration with the FTA. These surveys polled mainly small- and medium-sized agencies and illustrate the growth and uses of GIS in these agencies between 1993 and 2003. Chapter four synthesizes the results of five case studies on the use of GIS in large transit properties. The comparative analysis of their GIS programs highlights similarities as well as differences in emphasis in their GIS deployments. Chapter five describes in more detail the GIS programs in the five case studies. These agencies are among the leading users of GIS in transit and provide examples of innovation, some of which are unique to each agency, whereas some are more commonplace and provide pointers to the future uses of GIS in the transit industry. Finally, chapter six presents the conclusions of this synthesis project and makes some suggestions for future studies.

CHAPTER TWO

GEOGRAPHIC INFORMATION SYSTEMS TECHNOLOGY DEVELOPMENT

OVERVIEW

The GIS is one of the most innovative advances in the study of geography. Since its development in the 1970s, GIS has had a major impact on geographic analysis and on business practice in government and the private sector. Most transportation agencies now use GIS and Geospatial Information Systems for Transportation (GIS-T) is one of the largest users of GIS technology. The significant innovation that GIS provides is the ability to manage data spatially in layers and then overlay these layers to perform spatial analyses (*1*). Therefore, a roads layer can be integrated with a land use layer enabling a buffer analysis of the land uses within a given distance of the road. The capabilities of GIS have improved over the past three decades, and GIS now provide a wide range of tools for data management and analysis. In the early 1990s, GIS added specific tools for linear data management of transportation data that has proved to be extremely successful among transportation organizations (*2*). These capabilities enable transit agencies to georeference their bus routes, stops, timepoints, and other features to a digital street centerline file, and keep all these data in synch. Figure 1 shows an example of a transit viewer website from TriMet (Portland, Oregon). The bus stops and bus routes are overlaid on an aerial photograph of the area. The data integration and management is provided by GIS, which inventories and spatially indexes the bus stops, routes, and images. As this example shows, the power of GIS is now available through the Internet to the general public and is no longer the domain of the specialist.

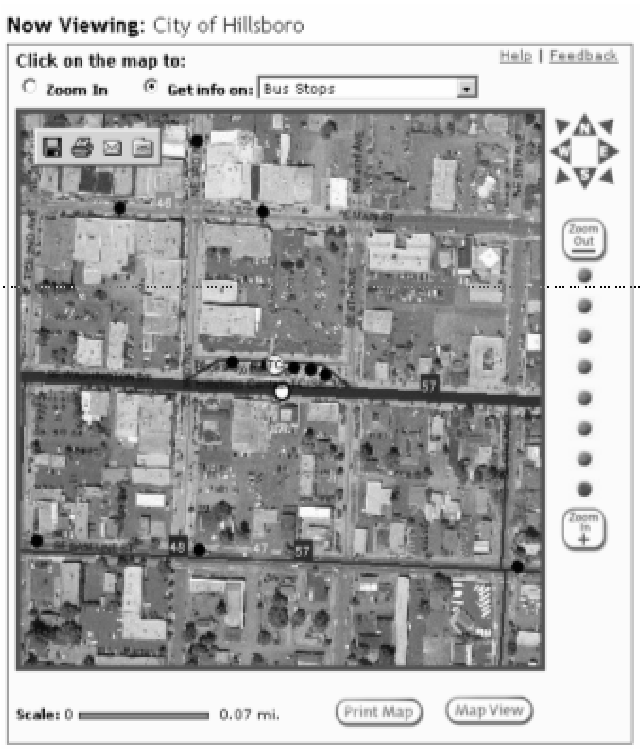

FIGURE 1 Web–GIS transit data viewer (TriMet).

There have been examples of the use of GIS in transit from the early days of GIS deployment in the 1980s (*3*). Some of these projects involved home-grown GIS products that were developed to take advantage of personal computers and advances in computer graphics (*4*). However, by the early 1990s, the GIS market consolidated around a small group of GIS vendors including ESRI, Inc. (Environmental Systems Research Institute), Intergraph, Inc., MapInfo Inc., and Caliper Corp. (Note: These represent the firms known to the author at the time of this research. Any error or omission is unintentional and no endorsement of these firms is implied.) Generally, the GIS vendors provide the GIS software and rely on third party developers or the users themselves to develop transit tools and applications.

Successful examples of transit GIS toolboxes developed on GIS platforms were found in the literature review and case studies. Many of these are located outside the United States, which demonstrates the success of GIS as a universal technology. Examples include the TOP (Transit Operations Toolbox) program developed in Copenhagen, Denmark; the ROMANSE (Road Management System for Europe) GIS-enabled trip planning system implemented in Southampton, United Kingdom, as part of a European Union-funded transportation infrastructure project; and the Integrated Transportation Management System in Singapore that includes GIS-based transit operations and planning. Also in Europe an economic interest group called TRUST (TRANSMODEL Users Support Team) has developed TRANSMODEL as a reference data model for public transport. Supported by the French government, TRANSMODEL was accepted in 1997 by CEN (the European Standards Institute) as an experimental standard. TRANSMODEL provides a detailed data model of public transport functions and transit data, but it does not include spatial data. TRANSMODEL has been linked to GIS in a test site in Salzburg, Austria, using the Geographic Data File (GDF) format (see section later in this chapter on Standards Initiatives). The small number of U.S. examples is documented in the literature review and case studies that follow.

The growing popularity of GIS has attracted the interest of transit software vendors who provide scheduling, vehicle tracking, and trip itinerary planning programs. In some cases, these vendors have developed their own mapping interfaces with GIS-type functionality. In other cases, they provide import and export programs to convert data into compatible GIS formats. These developments reflect in part the demands from the customers for mapping interfaces, but also that spatial data are needed in scheduling. This raises issues for transit agencies in how they integrate proprietary spatial data formats with their GIS programs. These proprietary formats have influenced the way that GIS is used in transit. Indeed, one of the issues that emerged from this synthesis project was the incompatibility between traditional transit programs and the newer GIS products. This issue also interfaces with transit data standards development and the institutional development of GIS programs vis-à-vis traditional centers of transit operations (e.g., scheduling) within the organization. These issues are discussed in more detail later in this report. They are mentioned here because of the way they affect transit GIS practice and, as apparent in the literature review, historically provide something of a fault line in GIS applications development. Although the barriers and tensions this presents are real, there are successful examples of how GIS and other programs have been integrated, as evident in some of the case studies.

The GIS vendors have also historically been somewhat reluctant to implement open standards for their products. More recently they have moved toward more open standards and most of the leading vendors are now members of the Open GIS Consortium (OGC), which promotes open GIS standards, including the Web Feature Standard (WFS) and Map Feature Standard (MFS). As web-based services become more prominent, mapping services over the web using XML (Extensible Markup Language) or GML (Geographic Markup Language), SOAP (Simple Object Access Protocol), Java2EE, and similar protocols that can work with WFS and MFS may open up a new era in GIS development. Already there are web–GIS applications that are independent of specific GIS formats, which have the potential to assist transit agencies, especially those that cannot afford a full GIS implementation. For example, it is now feasible to store geometry as a spatial object in some database management systems (DBMS), which replaces one of the key functions of GIS. These trends are important because, too often, GIS developments are evaluated from a vendor-specific viewpoint rather than considering the broader domain of GIS and IT capabilities to support transit business processes. If the next generation of GIS follows the trend toward web-based services, then services like mapping, geocoding, and transit analysis tools may be available on-line by means of a transit Internet Service Provider, thus weakening the dependency on specific GIS platforms. (Note: This is not a prediction nor is it being advocated, but it reflects trends already occurring in the wider IT community that offer more choice as to how software and data are managed and delivered to the user.)

Another interesting trend has been the convergence between geospatial technologies comprising GIS, GPS (global positioning system), and remote sensing technologies such as satellite images, LIDAR (Light Detection and Ranging), and products that orthorectify remote sensed data. This convergence is occurring in part because of IT compatibility and the overlap and complementarities between the technologies. Many users prefer the term "geospatial" to "geographic" information systems for these reasons. Within the academic community, GIS is seen as a technology application within the realm of geoinformation science. In the broader IT community, GIS is often referred to as geospatial information technologies (GIT rather than GIS), which has a harder IT edge to it; and sometimes as geomatics, which denotes geospatial data and processes as well as the technology. These terms may be interchangeable and somewhat duplicative and reflect the particular perspective of a community of interest. Nevertheless, their growing use signifies IT convergence and, at the same time, diversification in the use of geospatial technologies. Users are beginning to mix and match technologies to meet specific requirements. The challenge for GIS, especially the GIS vendors, has been to keep up with these demands and provide a one-stop-fits-all GIS package. In doing so they have inexorably become more "IS" and less "G"; hence, the distancing of some academics from the technology products and the return to fundamentals of "GIscience." As with all software tools there is a perceived danger in relying on the tool versus the analytical ability of the user. This raises concerns in some quarters, especially the research community, and could be an interesting topic for further research.

GEOGRAPHIC INFORMATION SYSTEMS BUSINESS ORGANIZATION

Broadly speaking, GIS has been applied at three levels within transit organizations. At the first level, when the technology is first introduced into the organization, its application is *project* based in areas like ridership analysis or bus stop inventory. At level two, the GIS technology matures in the organization and becomes more widely used as a *departmental* resource, supporting a broader range of functions in business areas such as route planning. Finally, at level three, it becomes a mainstream *enterprise* system that is part of the agency's IT architecture. Although some users have progressed through all three levels, the majority of transit GIS users are still at levels one or two. The

TABLE 1
LEVELS OF GIS BUSINESS ORGANIZATION

GIS Application Level	Business Model	Transit Archetype Organization	GIS Programs	Staffing
Project	Ad hoc opportunistic implementation, not a cost center or budget area. Focus on specific short-term transit activities	Small- to medium-sized agency with no central IT/GIS support	Management of base layers for transit data. Map-based query and display via standard GIS tools. Ad hoc desktop applications for geocoding, bus stop, and transit data analysis; simple demographic analyses	1–2 self-taught GIS specialists and a small number of other ad hoc users
Departmental	Part of department's business plan. GIS budget. May serve as a GIS service center to other departments	Medium-to-large transit agency with GIS unit or specialists within planning or operations departments	Broader use of GIS in the above areas plus programs to develop more sophisticated applications and tools for transit planning and operations	3–5 GIS specialists with regular users within the department and from other business units. Some training in GIS may be part of the business plan
Enterprise	Part of agency's IT infrastructure. Corporate planning and budgeting. Corporate service center (even if located within a department)	Large transit agency with R&D programs, planning and operations that utilize GIS. GIS provided by IT or specialist GIS unit	GIS data management and applications development integration with other transit software and information systems	5 or more GIS/IT specialists with broad range of skills from GIS programming to GIS/IT systems integration. GIS staff supported by other corporate IT resources. Large number of users across the agency

Notes: IT = information technology; R&D = research and development.

chances of progressing to level three are greater in a larger agency with more resources, but size is not the only factor that influences GIS development. Table 1 summarizes the GIS development levels and correlates these with the general business models that determine the role of GIS in the agency. Although no two transit agencies are alike, GIS archetypes can be generated.

GEOGRAPHIC INFORMATION SYSTEMS RESOURCES FOR TRANSIT

There are some key resources to assist transit agencies in implementing GIS programs and a number of case studies to provide guidance on the do's and don'ts for transit practice.

Vendors

Research publications often cite information provided by GIS vendors, such as case study examples of transit applications. The vendors can also provide information and contacts at their success sites. In some cases, they provide White Papers and data models as templates for transit GIS services, offering advice on implementation steps as well as indications of cost, technical resources, and data sources. They also provide training and consultant services directly or through their business partners. Further information is available from the following sources:

- ESRI: GIS for Public Transit Management—Case study examples are available on the ESRI website: http://www.esri.com/industries/transport/transit.html and in a publication on GIS-T (*5*). ESRI has also published the data architecture for their transportation data model, called UNETRANS (Unified Transportation and Network System).
- Intergraph—See website http://imgs.intergraph.com/transportation, where a copy of their Geotrans White Paper is available.
- Caliper TransCAD Transit Analysis—TransCAD GIS has specific extensions for public transit. (See website http://www.caliper.com/tcovu.htm#Transit%20Analysis.)
- MapInfo, Inc.—See website http://www.mapinfo.com, where transit examples are shown.

The spread of GIS across the nation means that GIS technical support services are available locally from a number of vendors and GIS consulting firms. In addition, GIS user groups that can offer support and advice on GIS issues have been formed in many regions. Generally, the level of technical resources available through these channels is high and reflects the maturity of the market for GIS services. These resources, however, come with a price tag and for smaller agencies just starting out in GIS the costs and level of effort to develop a

GIS program can appear daunting. For these reasons, many transit agencies have created GIS programs that use a mixture of in-house and contractor resources.

There is an informal GIS-T community comprising GIS users, vendors, and academics, which meets at conferences such as the Annual GIS-T Symposium, those sponsored by TRB, vendor conferences, and others. There are also professional groupings around specific issues such as standards development (described later) and transit research. There is no formal transit GIS group or forum. Transit GIS is therefore poorly represented among the GIS-T community, and one of the challenges for transit is raising its profile to ensure that it gets the attention it deserves and the GIS technology it seeks. There is much going on in the transit GIS arena, as evident in the findings of this synthesis, but few beyond the transit GIS community are aware of it.

Universities

There are several universities that provide courses and research in transit GIS including

- University of South Florida, Center for Urban Transportation Research (CUTR), which has an active transit GIS research program and was one of the sponsors of the National GIS in Transit conference (the third conference was last held at CUTR in 1999).
- Oakley GeoGraphics Laboratory, Bridgewater State College, Massachusetts, which maintains the National Transit Database (NTD) in GIS formats and in 1992 and 1993 performed surveys of GIS use in transit.
- The National Transit Institute at Rutgers University, which has conducted GIS research and workshops.
- Some of the universities that are members of the National Center for Geographic Information and Analysis have conducted transit GIS research, although most of its focus is on highways and aviation
- Other universities that have undertaken significant research include the Massachusetts Institute of Technology, Iowa State University, University of Wisconsin, Portland State University, and the University of Illinois at Chicago.

Universities have created many techniques for GIS in transportation including the widely referenced *NCHRP Report 460*: *Guidelines for the Implementation of Multimodal Transportation Location Referencing Systems* (*6*). They have cooperative research programs and internships that can benefit transit agencies.

FTA

The FTA has sponsored a number of initiatives in GIS. The National Transit GIS is a representative inventory of the country's public transit assets. Creation of this national system is an ongoing and collaborative effort on the part of many within the transportation industry. Use of these transit data can facilitate the exchange of information within the U.S. Department of Transportation (U.S.DOT) and throughout the transit industry. This effort supports the mission requirements of the U.S.DOT, particularly as established by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). Most notably, this includes the development of a GIS-based National Transportation System for transit routes as a major element of the National Spatial Database Infrastructure (NSDI). This spatially referenced database will provide transit planning and operations data such as population served, ridership, passenger miles, and route/rail miles for all modes of public transit. The systems and facilities include rural and urban bus systems, commuter rail, subways, light rail, people mover systems, high-occupancy vehicle systems, ferry terminals, and transit ways.

The Standards, Guidelines and Recommended Practices establishes a framework for maintaining the NTD, ensuring data integrity, interoperability, and consistency. The methods and quality control used in creating, storing, exchanging, and documenting the data in the National Transit GIS is known by recommending feature type definitions, formats, file formats, update procedures, and other standards. The document outlines feature type definitions and descriptions, addressing and street naming conventions, feature type automation and conversion guidelines, transfer formats, and update and maintenance procedures.

In 1992 and 1993, the FTA sponsored the GIS in transit surveys conducted by Bridgewater State College, where the spatial data sets for the NTD are compiled and managed (see http://www.fta.dot.gov/library/technology/GIS/ntgistds/NTGISTDS.HTM). Transit GIS publications can also be found on the Bureau of Transportation Statistics and the FHWA GIS websites http://www.bts.gov/gis/index.html and http://www.gis.fhwa.dot.gov/.

TCRP

TCRP previously prepared *TCRP Report 60*: *Using Geographic Information Systems for Welfare to Work Transportation Planning and Service Delivery* (*7*). The objective of that research was to develop a handbook providing guidance on the use of GIS for Welfare to Work transportation planning and service delivery. The handbook includes a brief review of current practices and recommended model approaches for applications of GIS to Welfare to Work. Supplementing the handbook is a CD-ROM that provides graphic examples of the program. The case studies included on the CD-ROM provide examples of the capabilities of GIS and are an excellent resource for the wider transit community, not just those involved in Welfare to Work programs.

Standards Initiatives

The FTA is one of a number of organizations that has been actively involved in developing data standards for the transit industry, including geospatial data standards. A driving factor behind this has been the Geospatial One-Stop (GOS) program initiated by the federal government. Other factors include the recognition from within the industry that incompatible standards result in inefficiency, duplication of data and applications, and unnecessary redundancy. Consequently, a number of industry forums have developed that, along with the GOS, have contributed to the development of transit data standards. The most important of these are the Transit Communications Information Profile (TCIP) (*8*), *Bus Stop Inventory Best Practices and Recommended Procedures* (*9*), *Location Referencing Guidebook* (*10*), and intelligent transportation systems (ITS) program.

GOS

The GOS initiative is a federal e-government initiative designed to expedite the creation of seven framework layers, one of which is transportation (*11*). The framework layer for transportation is being developed under the auspices of the NSDI project following guidelines laid down by the Federal Geographic Data Committee. In support of the transportation framework layer, a data content standard for transit has been created by a committee of experts known as the Transit Modeling Advisory Team coordinated by the BTS. It is being pilot tested in a few places. Transit agencies have some concerns about the incompatibility of the National Transportation Communication for ITS Profile (NTCIP) and GOS. The BTS has taken the lead in developing the transportation GOS standard. The primary purpose of the standard is to support the exchange of transportation data related to transit systems. In doing so, it aims to establish a common baseline for content of transit databases for public agencies and private enterprises. The content will be organized in metadata formats that will be supported by the vendors and user communities. For example, the Federal Geographic Data Committee has developed a metadata template for spatial data that at least one GIS vendor has incorporated into its GIS program. Benefits of adopting the standard include reducing the cost of acquiring and exchanging data; improvements in the geospatial transportation base data; improved integration of safety, emergency response, and enforcement data; and streamlined maintenance procedures.

At the time of this report, the standard had been submitted to the American National Standards Institute for review and comment. It complies with related standards developed by the International Standards Organization (ISO), specifically the Technical Committee on Geographic Information/Geomatics (TC 211), which produced ISO 19133 Tracking and Navigation Draft International Standard. The standard can be implemented using a variety of software packages and is designed to accommodate data encoded without geometry, as well as support the exchange of data encoded in a variety of GIS. It is also designed to be able to depict the complete transit system at all levels of service and all functional classes that may be defined by the transit agency. Thus, it provides a comprehensive set of transit features including bus stops, routes, patterns, segments, timepoints, fares, landmarks, facilities, amenities, block, trip, and geographic features. These features or entities of the transit system are related to one another in a transit system data model that describes the data content or base attributes of each feature.

As indicated, the transit standard appears to include most if not all types of transit data that are managed by transit agencies and outlines the relationship of these to the spatial data; that is, how the transit data can be referenced to the geospatial data to create a framework layer. However, there is concern that the standard will not be followed by commercial vendors, who code their applications to support specific business processes, such as scheduling or trip itinerary planning. So, although the content may be complete, how it is implemented may vary across applications and between agencies. How problematic this will be remains to be seen. According to the data model, features are logically related to one another based on real-world practice and should be robust enough to accommodate variants. Even so, there are transit programs that do not connect features logically or omit relationships that seem peripheral to their specific application. In these cases, the transit standard can serve as a checklist to identify gaps; but who is responsible to fix any omissions? And, are there any penalties for noncompliance? These are questions that need answering if the transit standard is to be successful.

Another ISO Technical Committee, TC 204, which develops and reviews standards for Transportation Information and Control Systems, has created the GDF standard mentioned in the Introduction. GDF is currently a published standard by ISO awaiting final review and comment prior to formal adoption, which could come as early as 2005. GDF is a detailed geospatial data standard for transportation including transit. It was originally developed to support ITS navigation services and has been incorporated by map vendors and some GIS vendors in their software. Therefore, it appears there are at least three standards that transit agencies need to be aware of (GDF, TC 211/GOS, and TCIP), which may affect their use of geospatial data as well as applications that use geospatial data. It is not surprising that confusion exists among transit operators as to which standard to adopt. There needs to be some coordination among the different standards bodies and transit-industry leadership to sort out some of the confusion. Part of the problem is that beyond the technical experts who participate on these standards initiative little information is known or circulated among the transit community. Most transit agencies, therefore, are unaware that these standards exist or are in development, and even fewer of them have been consulted as to their impact.

Bus Stop Inventory

Although not a standard per se, this is an example of another initiative sponsored by the FTA to provide guidelines to transit agencies. The bus stop inventory is a core data management tool for supporting planning, operations, maintenance, and marketing functions throughout an agency. It supports the deployment of advanced technology systems such as GIS, itinerary planning, APC, and automatic vehicle location (AVL). The guidelines describe collection, storage, and maintenance procedures as recommended by agencies and vendors who develop, implement, and use stop inventories. The *Bus Stop Inventory Best Practices and Recommended Procedures* report provides examples and templates on data content and design of the inventory including examples from field practice (*9*).

TCIP

TCIP is part of the NTCIP, which is a joint standardization project of AASHTO, the Institute of Transportation Engineers (ITE), and the National Electronic Manufacturers Association (NEMA), with funding from the FHWA. The TCIP development effort began under the auspices of the Institute of Transportation Engineers in cooperation with APTA, FTA, and FHWA. The TCIP family of recommended standards addresses Advanced Public Transportation Systems (APTS) data interfaces, related automated transit tools, and data. The standard, NTCIP 1400, TCIP Framework Standard, also address the business requirements of the APTS data interfaces.

As the name implies, the focus of TCIP activities is on communications of transit data, such as data packets between vehicles and roadside devices. With the increasing use of GPS and other location devices, the need to communicate location along with other information is critical. Examples include vehicle tracking and bus annunciation systems. As part of this program a Location Referencing Message Specification standard has been proposed (SAE J2266) that provides a message packet for transmitting location data. At the time of this synthesis, the standard was to go forward in 2004 to reballot by the Society of Automotive Engineers (SAE) Advanced Traveler Information System Committee, then to the SAE ITS council for final adoption. NTCIP/TCIP has already adopted standards for defining location referencing methods, for example, for points, lines, polygons, and routes, which a GIS needs to follow if exchanging data between TCIP compliant applications (see NTCIP 1405:2000, Standard on Spatial Representation Objects, Version 1.03).

The ITE, AASHTO, NEMA, NTCIP Joint Committee announced in September 2004, that management of the TCIP program was being transferred to APTA. In the meantime, the existing TCIP standards have been rescinded, effective September 30, 2004. This move appears to have been the result of APTA's refusal to sign the NTCIP Memorandum of Understanding; preferring to pursue its own TCIP standards development. This change reflects some of the confusion and overlap in transit standards development. As a result of the transfer, APTA, which represents the transit industry, has agreed to coordinate with the NTCIP and will assume intellectual property of the TCIP standards developed under the auspices of ITE/AASHTO/NEMA. It is hoped that this will lead to clarification of standards, roles, and organizational responsibilities.

Best Practices for Using Geographic Data in Transit: A Location Referencing Guidebook

Sponsored under a cooperative agreement with the FTA, this guidebook was developed at the request of the transit industry. It provides best practices for both transit managers and technical staff with respect to planning, implementing, and using geographic data in transit. The guidebook discusses issues and best practices for defining and using geographic locations of bus stops, routes and other map data that are needed for successfully implementing ITS and GIS, as well as for obtaining operational efficiencies. The first phase of the project involved a feasibility study to assess transit needs and available standards. The second phase focused on producing the guidebook to summarize and synthesize standards for using GIS and location referencing. Published in October 2003, the guidebook provides a comprehensive overview, and in some areas a detailed description, of existing standards and practices (*10*). It includes 10 technical appendices and a detailed glossary. Readers who wish to review GIS and transit in a single publication should refer to this document, which when published could become the "text book" for transit GIS implementation, including guidance on how to move from a project-level GIS to a department- and enterprise-level implementation. This synthesis uses some of the same information and information sources as that report.

ITS for Transit

ITS comprise a range of advanced technologies that collectively aim to improve the safety and performance of transportation. Transit is one of the core areas of ITS. Much of the focus on ITS is in the arena of standards development, such as NTCIP, and the development of regional architectures that are mandated by 2005. Failure to create a regional ITS architecture may jeopardize federal funding of ITS projects. The following brief discussion summarizes the transit elements of the transit ITS architecture. A full description is available on the ITS architecture website: http://itsarch.iteris.com/itsarch/.

The National ITS Architecture provides a common framework for planning, defining, and integrating ITS. It is a mature product that reflects the contributions of a broad cross section of the ITS community (transportation practitioners, systems engineers, system developers, technology specialists, consultants, etc.). The architecture defines

- The functions (e.g., gathering traffic information or requesting a route) that are required for ITS.
- The physical entities or subsystems where these functions reside (e.g., the field or the vehicle).
- The information flows and data flows that connect these functions and physical subsystems together into an integrated system.

Table 2 lists the transit functions and associated subsystems within the ITS architecture. The geospatial data management and map update services are part of the archived data subsystem.

TABLE 2
ITS TRANSIT USER SERVICES

Function	Subsystem
Public Transportation Management	Public transportation management
	En-route transit information
	Personalized public transit
	Public travel security
Information Management	Archived data function (including geospatial data and map update)

To fully maximize the potential of ITS technologies, system design solutions must be compatible at the system interface level to share data; provide coordinated, areawide integrated operations; and support interoperable equipment and services where appropriate. The National ITS Architecture provides this overall guidance to ensure system, product, and service compatibility and interoperability, without limiting the design options of the stakeholder (Figure 2). The ITS architecture illustrates at a high level how the transit functions and subsystems—travelers, vehicles, transit management, and safety—are linked together by means of the communications protocols.

In deployments, the character of a subsystem deployment is determined by the specific equipment packages chosen. For example, a municipal deployment of a Transit Management Subsystem may select Trip Itinerary Planning and Vehicle Scheduling equipment packages, whereas a state traffic management center may select Trip Itinerary Planning and Automatic Vehicle Location packages. In addition, subsystems may be deployed individually or in aggregations or combinations that will vary by geography and time based on local deployment choices. A traffic management center may include a Trip Planning Subsystem, Transit Information Provider Subsystem, and Emergency Management Subsystem, all within one building, whereas another traffic management center may concentrate only on the management of traffic with the Traffic Management Subsystem.

Although GIS may not be one of the subsystems or identified elements of the ITS architecture, Map Update Provider is a recognized key process for managing location-based information and location-based services for transit operators and their customers, and it feeds a number of subsystems and services such as AVL. GIS can play an important role in implementing ITS, especially where location data needs to be exchanged between the different subsystems or where the subsystems need to share a common base map and location referencing system. ITS provide something of an umbrella framework for many of the other standards development discussed previously above.

TRANSIT GEOGRAPHIC INFORMATION SYSTEMS APPLICATIONS

The literature review discovered more than 130 publications on GIS in transit. Table 3 summarizes these by application categories. Not surprisingly, some publications cover more than one category; however, as far as possible they are assigned to the category that is the primary focus of the publication. Furthermore, some articles are not entirely focused on transit but include transit alongside other transportation modes. For these reasons, the transit orientation of the article is also recorded as being high, medium, or low. High means it is focused entirely on transit, medium indicates equal consideration of transit alongside other modes, and low includes transit, but not prominently.

The discussion that follows will focus on those publications with a high transit orientation. An annotated bibliography of some of these publications is provided following the references. Not surprisingly, the categories with the most publications are planning and IT, which between them account for 77% of the literature. For each category, examples of transit applications in the three levels—project, departmental, and enterprise—are provided where available. These examples are representative of the types of uses of GIS among transit agencies and give a flavor of the wide range of applications that are capable with GIS.

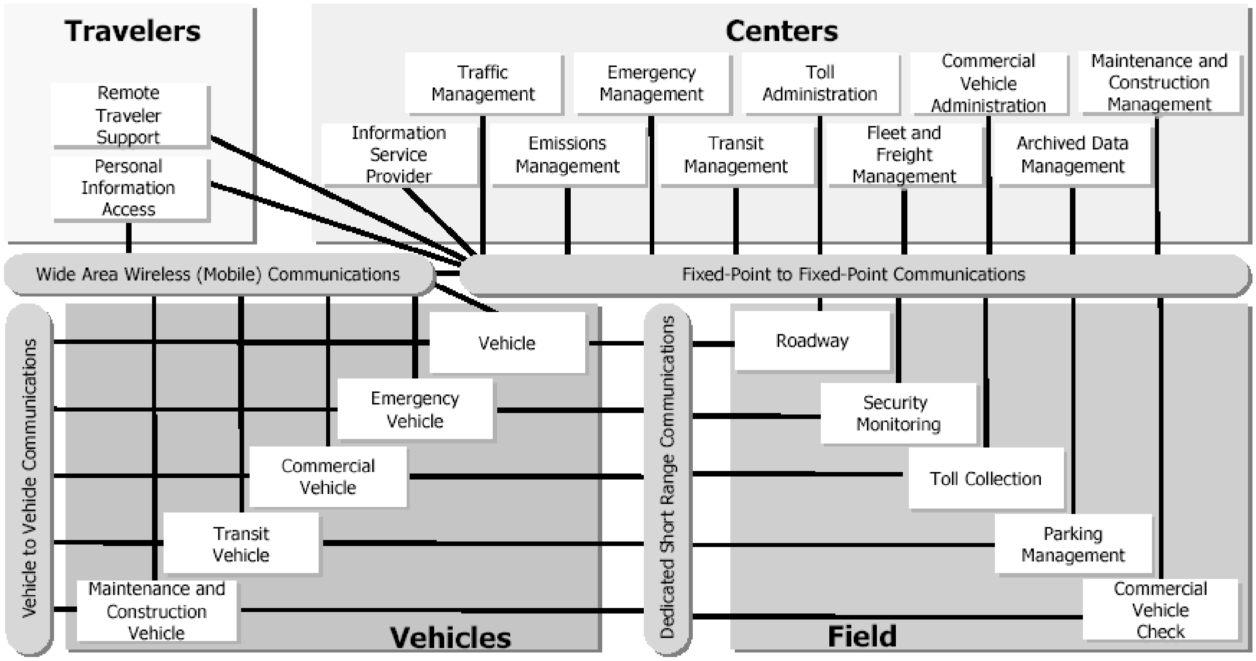

FIGURE 2 ITS high-level architecture diagram.

TABLE 3
TRANSIT GIS PUBLICATIONS BY CATEGORY

Category	No. of Publications	Transit Orientation (1 = high, 2 = medium, 3 = low)
Planning[a]	59 (46%)	1: 35 2: 15 3: 9
Information Technology[b]	40 (31%)	1: 20 2: 12 3: 8
Operations[c]	13 (10%)	1: 7 2: 3 3: 3
Management[d]	12 (9%)	1: 6 2: 1 3: 5
Customer Service[e]	5 (4%)	1: 5 2: 0 3: 0

[a]Planning, including route and facility planning, automatic passenger counting systems, ridership reporting, demographic analysis, and modeling tools.
[b]Information technology, including hardware, software, custom tools, and standards.
[c]Operations, including vehicle and facility maintenance, vehicle location, routing and scheduling, and real-time traffic information.
[d]Management, including safety, security and incident response, system performance and reporting, asset management, and finance.
[e]Customer service, including trip itinerary planning, customer relations, real-time customer information, public information, and marketing.

Planning

Planning, including route and facility planning, APC systems, ridership reporting, demographic analysis, and modeling tools has traditionally been a strong area for GIS applications and includes the foundation infrastructure for GIS such as the base map, transit network, bus stop, and route inventories. There are examples of GIS applications in all sizes of transit agencies, from small rural to large urban operators. Typical of the rural applications is the Shenandoah Valley Public Mobility Project (Virginia), which is using GIS to coordinate the transportation of human service organizations (*12*). They have been assisted by the Smart Travel Lab at the University of Virginia to use GIS to visualize the current transportation services provided by these agencies and to look for possible overlaps. The routes that agencies run on a regular basis are represented in ArcView by line segments. These routes are then layered on a map of the Lord Fairfax Planning District and some simple analysis is done on the routes, such as buffering. One possible outcome is a web-based system that contains all the routes and allows a user to search for the best route for a potential client between two points. This project-level application demonstrates the usefulness of GIS in compiling and visualizing transit information, and also shows the benefit of getting support from another organization with GIS experience. In this case, it was a local university, but elsewhere transit agencies have often sought support from their colleagues in another local agency.

There are several other examples of how GIS is being used to provide mapping and analysis tools. In Corpus Christi, Texas, the Regional Transit Authority and Texas A&M University–Corpus Christi have developed a GIS that includes the street maps for the three county service regions, the route system, and the bus stop locations. These maps are used together with U.S. Census Bureau block and block group information to perform communication, analysis, planning, and service assurance. A GPS could also be used to support AVL and data collection (*13*). At the statewide level, GIS has been used to compile information on transit services and for evaluating levels of service for planning purposes. Maryland and Florida are two states that have created statewide transit databases. The Maryland Transit Administration developed their database to support the NTD program mentioned earlier (*14*). In Florida, they created a statewide transit GIS for a Transit Technical Assistance Program to local systems (*15*). Many of these systems are limited in their ability to hire experienced GIS transportation professionals. The technical assistance will enhance the work performed by the agency's GIS professionals and will introduce transit planners to the potential uses of GIS.

At the department level there are examples of the broader use of GIS to support many agency functions. GRTC Transit, the public transportation agency serving Richmond, Virginia, and Chesterfield County, Virginia, has created a GIS to improve its route planning process and to track assets (*16*). The system has helped the agency adjust its routes to serve the rapidly growing population in central Virginia and to keep its asset inventory current. GIS and GPS capabilities allow for new perspectives on the planning process for transit applications and the analytical tools that such technology provides. GIS technology is therefore helping to integrate decision making at GRTC. This is a good example of the development and implementation of GIS technology in a mid-sized transit agency.

At the enterprise level, the Metropolitan Transportation Commission (MTC) in Oakland, California, is building a regional transit information system (RTIS) and regional transit database (RTD) for the San Francisco Bay area (*17*). The primary objective of developing this enterprise architecture is to not only foster cooperation and information exchange and interoperability among transit operators, but to also provide the public with more comprehensive and easy access to the transit information. The San Francisco Bay area comprises 9 counties and 100 cities, with a combined population of more than 6 million, and it is served by 26 different transit operators, including the metro rail system—Bay Area Rapid Transit. A primary objective of this RTIS is to provide comprehensive and accurate transit information to the user in the most efficient manner. A key element of this architecture is an RTD that will be a repository for all transit data and related spatial information for all regional applications. GIS technology is a core foundation for the RTIS and the Take Transit trip itinerary planner both for managing the geographic and transit data and providing it over the Internet.

Other examples of enterprise use of GIS can be found in King County Metro (KCM; see the case study in chapter five) and in publications on the Orange County Transportation Authority (OCTA; California) (*18*), and the Tri-County Metropolitan Transportation District of Oregon (TriMet; Portland, Oregon) (*19*). These transit agencies were among the first to use GIS and have gradually expanded the scope of GIS within their respective agencies. TriMet is another of the case studies included in this synthesis (see chapter five). OCTA has pioneered a number of innovative projects with GIS and in 1997 won an innovation award from the American Planning Association for its detailed analysis of ridership patterns. These types of analyses have helped OCTA adjust its bus service patterns to more accurately reflect customer needs. The FTA and FHWA recognized OCTA's pioneering use of GIS in transit planning and made a case study of the agency in 2001.

There are also publications on how to create an enterprise GIS-T. Ford and Widner (*20*), for instance, analyze ways of partnering to share transportation data among state and county governments, using Virginia as a case study. They define four levels of data partnership, from informal arrangements to cooperative agreements. They note that enterprise approaches provide the most comprehensive datasets capable of supporting multiple applications, but require formal agreements on the data model, formats, road and transit definitions, attribute sources, accuracy, and data security. This is quite a shopping list and needs the support of management as well as technical users if it is to be successful. Attanucci and Halvorsen (*21*) review the capabilities provided by GIS and describe, by example, how a number of transit agencies are currently using these programs. In addition, a hypothetical comprehensive GIS is envisioned to show how a service and operations planning unit can take full advantage of today's GIS features. The resources required to establish a transit GIS are also discussed and a candid assessment of various obstacles to establishing a full-featured transit GIS is made.

IT

IT, encompassing hardware, software, custom tools, and standards, includes articles on how to implement GIS from a technical perspective. Within this category are many technical research papers from universities as well as documents and reports on GIS standards. At the project level, there are several publications that describe the GIS technology needed to address specific problems. Kratzschmar and Zhou (*22*) describe one implementation of the infrastructure needed to facilitate the sharing of geographic information between data providers and service providers, using real-time bus locations as an example of using the Internet to deliver geographic content to the user's browser and desktop. Web-based transit information systems are the subject of several research projects such as the development of a GIS architecture for a transit website in Montreal and Internet GIS approaches to transit information design (*23–25*). There is also some interesting research on GIS-based algorithms for transit scheduling and trip itinerary planning (*12*,*26*).

There are several examples of GIS technology projects at the department level. The Utah Transit Authority has been making GIS and transit ITS technology work together (*27*). The integration of GIS analytical tools and transit ITS technologies has provided opportunities for changes in transit system design. The results have improved service and changed the political climate surrounding the development of transit services. The San Diego Association of Governments has created Estops, an on-line GIS-based transit stop inventory maintenance tool that is shared by agencies throughout the region (*28*). Previously, multiple inventories were used to maintain the same stop information. This not only increases the effort, but also increases the chance of error by increasing the redundancy of data. To reduce the stop inventory maintenance effort and centralize the stop inventory database, the San Diego Association of Governments initiated this project to let all transit operators maintain their own stop inventory data in a centralized database by means of a secured website.

At the enterprise level, there are fewer examples of GIS systems architectures that integrate GIS with the agencies' information systems. In the chapter on case studies, some of the latest examples are described. Because the enterprise approach to transit GIS is very recent the publications are few and focus on a high-level overview with only one or two practical demonstration projects. The RTD project at the MTC is one of the leading examples (*29*). In this project, the MTC is implementing a new architecture for the data integration and data management including spatial data. The information is being used for trip itinerary planning as well as for building databases on bus stops, routes, and other transit features for planning and customer information applications. A unique feature of this project is the customization of a trip planning system to operate in a GIS-compatible environment. This is possible because the trip planning software—TranStar—was acquired from the Southern California Association of Governments rather than a commercial vendor. The MTC owns the source code and can therefore amend the program to embed GIS in its trip planning system, not simply link to an external GIS program. TriMet has also been using GPS technology to collect and maintain transportation data in collaboration with the agency's GIS program (*30*). TriMet has recently increased the positional accuracy of 8,000 stop locations along bus routes and light rail. Digital images were also gathered along with stop amenity information and these are currently maintained using GPS. All TriMet buses are currently equipped with GPS units that capture more than 600,000 observations of data on a daily basis. On-board computers and AVL equipment link with the bus dispatch center to improve communications with the bus operators, locate buses in real-time, and enhance data collection. Automatic passenger counters capture information while the GPS date and time stamps the record along with the *XY* coordinate location. This information is now routinely aggregated for passenger census at stop and route level. A centralized database allows users to access current data dynamically for spatial and temporal analysis. For example, internal customers have access to real-time bus location information, and external customers can use the Transit Tracker application, which predicts the next arrival time of a bus, through the web or at selected bus stops.

Finally, there are some reviews of systems integration issues in transit agencies (*31*). Transit agencies use many transportation accessory packages such as paratransit, scheduling, trip planning, and ride sharing and carpool software. There is a need to analyze data from these applications in a GIS, but importing the proprietary data formats into GIS or other application packages can often be difficult and time consuming. Although many vendors offer packages of modules that are designed to meet all the needs of an agency, the reality is that no one set of applications can satisfy the needs of an entire organization. To integrate these separate but essential systems it is necessary to develop a cost-effective method to plan for the integration of these products. Examination of integration issues in both DOT and transit agencies indicates the need for strategies that improve data access and reduce application maintenance costs.

Operations

As GIS technology has matured, it has moved beyond the display of static data to link with programs that are at the core of a transit agencies' function, namely scheduling and vehicle monitoring. From the perspective of the transit operator, a basic unit of analysis is the bus trip. Although varying in format, each transit property maintains a complete list of bus trips for each of the several regular schedules it accommodates (e.g., weekday, Saturday, Sunday, and holiday). This temporal aspect makes it more complex. Real-time adjustments to these assignments in response to unanticipated events (e.g., bus breakdowns and nonrecurrent congestion) are performed by supervisors in the field and, increasingly, by means of centralized AVL and control systems. Longer-term and systemwide assessments of operational performance require the collection of vast amounts of data that must be organized to reflect complex temporal (e.g., morning peak, base, and evening peak) and spatial (e.g., in-bound by route or corridor) patterns. Automated data collection techniques are slowly replacing manual methods in this area as well. One consequence of automated data collection is the added volume of information in need of processing and analysis. Therefore, bus operations analysis is a data-intensive area that can be substantially enhanced by spatial visualization in a GIS framework.

Most of these applications occur at the enterprise level, but there are some approaches that include project-level and department-level perspectives. An example of the project approach is the application of GIS to the monitoring of bus operations. Bus operations analysis is a data-intensive area that can be substantially enhanced by the topological overlaying capabilities and spatial visualization afforded by a well-designed and methodically developed GIS framework. One study reviewed the major types of data usually collected by bus properties and the typical uses to which these data are put, identified spatial and attribute data organization requirements that are of particular relevance to bus network structures, and developed a prototype GIS application to the monitoring of schedule adherence (*32*).

There are examples in the literature of paratransit and rideshare services using GIS to geocode passenger trip origins and destinations to try and match up the passengers to vehicles or to other passengers for ridematching. The development of on-line rideshare matching to provide convenient choices for the commuter and reduced operating costs to transit operations are being developed for the Virginia Department of Rail and Public Transit (*33*). The application uses web and GIS technologies. This agency provides support to 15 local rideshare and transportation on demand management agencies through grant programs by conducting research, and by providing training and communications and marketing assistance. The program was built on GIS without which it would have been difficult to implement.

At the enterprise level, some of the larger transit agencies have implemented AVL systems as part of a comprehensive transportation management program. These systems include GPS, CAD (computer-aided dispatch), and GIS, together with the communications devices. They enable real-time monitoring of transit vehicle locations and are used to manage incidents, bus bunching, and other operational issues. Some of the case studies cited in chapter four are implementing these systems. Because of their complex systems integration, these systems are costly and mainly provided by large IT companies. An excellent review of the state of the art of these systems is provided by Casey et al. in *Advanced Public Transportation Systems: The State of the Art Update 2000* (*34*). The report reviews AVL systems in Portland, Oregon; Essex County, New Jersey; Chicago, Illinois; Baltimore, Maryland; and Rochester, Pennsylvania, including their use of GIS. (A related report, *Advanced Public Transportation Systems Deployment in the United States*, contains a complete survey of AVL systems in use nationally in 1999) (*35*).

Management

This area includes safety, security, incident response, system performance and reporting, asset management, and finance. It is the area of interest to managers and is also the area with the least focus on technical issues and details. There are examples of specific project-level applications of GIS especially in safety, incident response, and asset management. In King County, Washington, for example, the transit division tracks security-related incidents on its transit system. Its older systems were unable to combine these data with spatial analyses crucial in deploying security resources to the needed areas in a timely manner. A GIS was implemented, along with other DBMS, and proved effective in supplying information needed by transit authorities and security personnel to decrease security incidents. The combined application was versatile enough to also assist other departments of the transit division (*36)*. Kurt et al. (*37*) has described how GIS can be used to develop an integrated asset management system for rural and small urban transit.

There are only a few publications on how to use GIS to monitor performance or provide decision-support tools for policy analysis. The FTA has used GIS in preparing its Annual Performance Plans and GIS is promoted as an innovative technology to assist transit agencies improve planning and service delivery. Some research papers address the current state of transportation planning as related to GIS usage. They seek to answer the question "How can geospatial data technology and GIScience contribute to improving our transportation system?" One example uses scenarios in transportation planning, including perspectives from a state DOT, a metropolitan planning organization (MPO), a transit administration, and a small state-funded nonprofit handling ride-share information. It then addresses current models and considerations and goes on to outline future policy considerations (*38*).

Managers are very interested in the costs and benefits of GIS programs. There are few examples of this in the literature; however, the *Transportation Case Studies in GIS* sponsored by the FHWA between 1999 and 2001, presented an evaluation methodology and produced statistics to demonstrate the tremendous benefits derived from a well-thought-out and supported GIS program (*39)*. Generally, however, beyond the examples cited, there are few guidelines or reports that address management of GIS in transit agencies. There is a need for more studies in this area. For instance, managers need to know what the resource requirements for an effective GIS program are and how to measure the benefits to the agency.

Customer Service

Among the very few publications on customer service uses of GIS in transit are two that highlight GIS applications in trip itinerary planning (*40,41*). Customers who inquire about transit service benefit from having maps of transit routes or walking directions to the bus stop, and there are some examples of these services being provided through the Internet. Customers also value real-time information on bus status. To provide transit information with GIS analysis functionality on the World Wide Web requires a system architecture that integrates web serving, GIS processing, and database management. It also requires an efficient pathfinding algorithm to handle the unique features of the transit network; for example, time-dependent services and multiple service routes serving the same street.

At the project level there are descriptions of system architectures that link the web-based graphic user interface, the Web server, and the GIS server. A GIS server is composed of three distributed components including map server, transit network analysis, and relational DBMS. Some of these publications are the result of research rather than actual implementations; however, there are some reports that provide information and guidelines on how to implement GIS and trip itinerary planning systems. A 2002 state-of-the-practice review of trip planning systems includes some implementation examples of GIS (*42*). These demonstrate both department- and enterprise-level implementations of customer service with GIS.

Another emerging area for GIS use is in the marketing of transit services. Zhou provides an example of how to apply GIS to a market segmentation analysis of transit riders (*43*). GIS can also be used to plot customer responses to surveys on service quality and to analyze origin and destination data for improving services and identifying new markets.

SUMMARY

This literature review demonstrates the variety of uses of GIS in transit planning, operations, information systems, management, and customer service. It is evident that the use of GIS in transit is growing and the technology is now mature enough to be considered a core technology in transit service delivery. GIS applications are moving beyond the traditional areas of planning and information systems, into operations, management, and customer service. The public is becoming more accustomed to on-line maps, and transit programs that do not include maps lack visual appeal. Even so, the growing use of GIS in transit is not merely cosmetic; customers are demanding real-time information for trip planning and trip reliability. To remain competitive with other modes real-time data are important.

There have been significant advances in GIS technology, in its user friendliness and capabilities to link to non-GIS programs such as scheduling, trip itinerary planning, and AVL. GIS enables these other technologies and can present the information to the public in an understandable visual manner. From an operational perspective there are benefits in being able to track and monitor transit assets. One of the fundamental applications of GIS is in managing the inventory of transit routes, stops, and schedule information together with the underlying street network. These elements can be synchronized in GIS so that if changes occur in any one of them the others will simultaneously be updated. This ability to synchronize the geospatial data with transit data is a major benefit of GIS. Any data with a georeference can be added to the GIS, thus expanding the scope and scale of the GIS. As revealed in the literature review, the scalability and flexibility of GIS use in transit is one of its most important features.

Recognizing the value of GIS in transit, the federal government and industry groups have been promoting the use of GIS technology and have created standards and guidelines for its implementation. A number of partnerships have been formed between government, industry, and interest groups to provide advice and support to transit agencies implementing GIS. There are plenty of reasons, therefore, to take advantage of GIS, as the next chapter illustrates.

CHAPTER THREE

SURVEY FINDINGS OF TRANSIT AGENCIES

INTRODUCTION

This chapter uses information from the web-based survey on the use of GIS in the transit industry as conducted by the GeoGraphics Laboratory, Bridgewater State College, in 2002 and 2003. The results of the 2002 and preliminary results of the 2003 surveys are reported and compared with the information in the literature review to reveal trends in the use of GIS. The web-based survey updated the FTA survey efforts in 1991 and 1994. The latest survey results can be found at www.e-transit.org/survey/. This website also lists the respondents to the 2003 survey. The survey instrument can be accessed on the Moakley Center, GeoGraphics Laboratory website at www.e-transit.org.

The methods of distribution of the survey request accounted for differences in the responses between 2002 and 2003. The 2002 survey yielded 74 responses and there were significant geographic disparities between FTA regions; some regions had no responses and some had very significant responses. The 2003 survey, sent directly from the GeoGraphics Laboratory to e-mail addresses in the FTA NTD, had a somewhat increased response rate (104) and wider geographic coverage than the 2002 survey. Both surveys, however, lacked adequate returns from larger transit agencies, even though the FTA surveys of the 1990s indicated that some large transit properties were already active in applying GIS technology at that time. This was the primary reason why it was decided to focus on case studies of large transit agencies in this synthesis to balance the results of the 1993 survey.

BACKGROUND

In 1991 and 1994, the FTA surveyed the industry for its use of GIS. Since then, geospatial information systems (a broader concept including more technologies) have advanced dramatically in their ease of use and computing power. The integration of spatial data from GPS, including AVL systems installed on transit and paratransit vehicles and high-resolution remotely sensed imagery from satellites into geospatial information systems, has pushed the state of the art beyond most early expectations for "geographic" information systems. The FTA has promoted the transit applications of geospatial data collection and analysis in ADA (Americans with Disabilities Act) compliance, Welfare to Work, Title VI (Civil Rights Act) compliance, rating supportive land use for New Starts capital projects, the promotion of transit use to national parks, customer information enhancements, coordinating human services transportation (HST), and now, antiterrorist measures to protect transit infrastructure and services.

In cooperation with the FTA, the GeoGraphics Laboratory revised the FTA survey of current GIS use to include the broader technological advances in GPS applications and remotely sensed imagery. The survey was designed to be conducted on the Internet for ease of use and administrative efficiency. The objective was to get a deeper understanding of the many innovative ways that the transit industry is applying geospatial tools to respond to our 21st century challenges. The survey incorporated as many of the questions from the earlier 1990s FTA survey as possible to create a time series for historical analysis. This synthesis focuses on the results of the most recent surveys.

RESULTS

The results are presented as an abbreviated summary of the 2002 and 2003 surveys, focusing on the changes of significance to opportunities for GIS applications.

Current Use of GIS by Transit Agencies

In the first FTA GIS use survey in 1991, more respondents answered that they did not use GIS than those who answered in the affirmative (Figure 3). Since that time, the opposite has become true. In the 2002 survey, 50 agencies responded that they currently used GIS and 24 indicated that they did not. In the 2003 survey, 77 respondents (74%) indicated that they currently used GIS and 27 that they did not (see Figure 3). Notwithstanding that a considerable number of larger and presumably more technology-oriented agencies were absent from both surveys, it is reasonable to assume that there is currently considerable growth in the application of GIS among medium-sized transit agencies. The increase in GIS applications in transit may be the result of the increasing ease of use and lower cost of GIS software for entry-level users. There are also more high quality geographic data products from government and private vendors that make GIS applications more useful to transit planners and analysts.

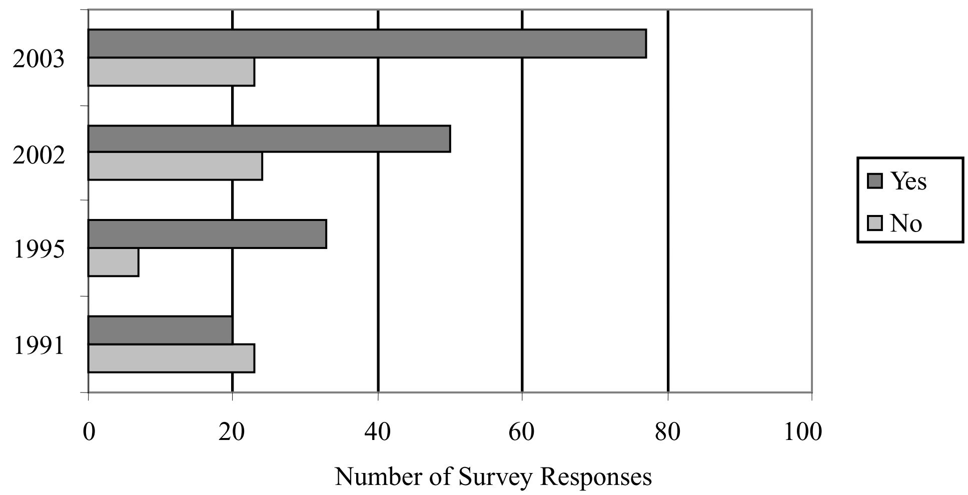

FIGURE 3 Transit agencies using GIS, 1991–2003.

Areas of Organization Where GIS Is Used

Figure 4 shows the GIS application areas mentioned by the 2003 survey respondents. The most popular applications continue to be the traditional areas, including map products, service planning, scheduling, and market analysis. The transit industry is also applying GIS to FTA policy and program areas, including Title VI (Civil Rights Act), Welfare to Work initiatives, ADA compliance, New (Rail) Starts analysis, and HST (paratransit). Although the number of responses preclude any definitive conclusion about the rates of change between 2002 and 2003, it is clear that in the area of civil rights compliance, such as Title VI and ADA, there is a clear geospatial component to preventing discrimination at the local level that may account for increasing GIS use in these areas.

A significant amount of change was registered between 2002 and 2003 in those transit industry topic areas that have inherent spatial and temporal characteristics (two areas that are addressed by GIS technology). The areas of biggest growth are service planning, trip planning, paratransit scheduling (assisted by GIS), AVL systems, and transit electronic fare payment systems collected with onboard GPS. The increasing use of GIS in operations such as trip planning and AVL are a reflection of consumer-driven applications of GIS. These trends would be more evident but for the omission of the larger transit systems that generally are more technologically advanced than smaller systems. A significant undercount in these applications may be inherent in these data. Regardless, the trend toward using locational technologies in transit is clear.

GIS Products

Although the sample size and type of respondents in the two surveys preclude any real conclusions related to market penetration by various vendors, the three vendors most often cited are Environmental Sciences Research Institute (ESRI), Caliper Corporation, and Maplnfo. This is similar to the finding of the literature review.

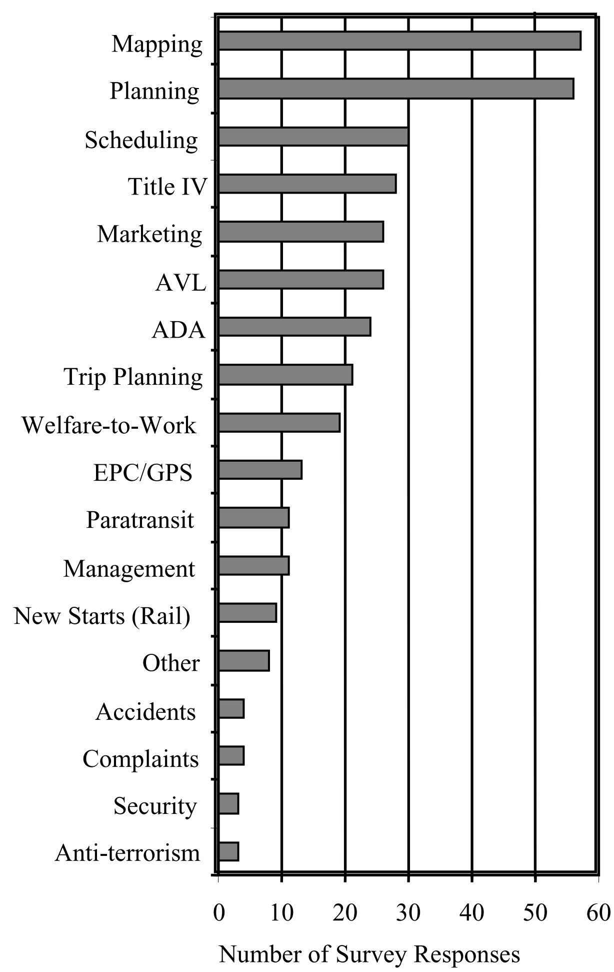

FIGURE 4 GIS application areas: 2003 GIS survey.

GIS Benefits

The 2002 and 2003 surveys did not attempt to quantify benefits from the deployment of GIS. Rather, respondents were provided with an opportunity to answer the question, "How has GIS use benefited your organization?" Some comments that capture the range of responses are presented in Appendix C. Briefly, the comments echo the benefits of using GIS as described in the literature review, including:

- Allows for the capture, analysis, and distribution of a greater volume and complexity of data;
- Improves communications with decision makers and the public through visualization of transit data. For example, better ability to visualize ridership data and bus stop information for greater comprehension of ridership patterns;
- Matches bus routes with demographic data to improve service quality;
- Increases productivity, improves interagency sharing, and coordinates geospatial information;
- Provides an excellent tool for analyzing policy issues (population served, market share, potential ridership, etc.);
- Assists in the development of paratransit maps for ADA compliance to illustrate the percentage outside of fixed-route system boundary;
- Assists in vehicle monitoring and in resolving issues with vehicle schedules;
- Enables automated trip itinerary planning, thus enhancing strategic and service planning capabilities;
- Provides APC capabilities for bus and light rail plus a distributed analytical tool for route effective and efficiency analysis through GPS and GIS integration; and
- Aids in the development of applications for regional planning, including regional travel models, Welfare to Work analysis, and socioeconomic projections.

Desired Improvements in GIS Capabilities

The 2002 and 2003 survey respondents were asked what type of improvements they would like to see in their GIS capabilities. Responses were varied and wide ranging. Generally, they fall into the following categories:

- Management appreciation and support for the GIS program,
- Extending the GIS with Internet-based mapping and web–GIS services,
- Additional staff resources and training needed,
- Continuous improvement in base map accuracy and currency of transit data,
- Data sharing and exchange with other agencies, and
- Use of GIS with operations programs including AVL and trip itinerary planning.

Source of Street Centerline Database

Early in the application of GIS by the transit industry the acquisition of street networks was a major issue. The concerns were the accuracy of the attribute data (e.g., street names), the currency of the data (e.g., updated information for streets in new developments), and the resolution of the data (e.g., the locational accuracy at large-scale projection). Transit GIS in the 1980s relied on the U.S. Census Bureau Dual Independent Mapping Encoding (DIME) files to develop a street network on a mainframe computer. The GIS analyst of the 1990s could use a desktop computer and the U.S. Census Bureau's Topologically Integrated and Geographic Encoded Reference System (TIGER) files for developing a GIS street network with a scale of 1:100,000. The analyst of 2002 and 2003 is using data products from the U.S. Census Bureau's TIGER files, state DOTs, and other sources (largely identified as agencies of local government) or commercial map vendors for timelier and geographically accurate data for street networks. In the 1990s there was much concern about the quality of the available data and the amount of staff time it took to make street networks serviceable for transit industry needs. In the 2002 and 2003 surveys, government and private vendors appear to have solved this problem for most agencies. This is a significant improvement over the past decade and one of the supporting reasons why use of GIS is more widespread.

Transit GIS Databases

In the early days of applying computers to bus operations, nonspatial databases were developed to capture the spatial characteristics of linear routes by storing the street intersections for routes, timepoints, and bus stops. With the availability of GIS, spatial data was defined by points, lines, or polygons using latitude and longitude and their relationship to other geographic features. The 2002 and 2003 surveys show an increasing use of GIS databases to describe the characteristics of transit, which is essentially a geographic business of moving people through space and time. Considering that when the FTA developed GIS databases of transit bus routes in 1994 and 1995 there were very few GIS route databases in existence, it is significant that this survey of predominantly small- and medium-sized transit agencies showed that 67 systems in 2003 had GIS databases of bus routes (Figure 5). Lastly, GIS bus stop inventories seem to be developing rapidly, as 27 were reported in 2002 and 51 in 2003. In the 1990s, very few transit agencies had GIS databases of bus stops.

Integration of Remotely Sensed Images

The Transportation Equity Act for the 21st Century (TEA-21) created a program to encourage the application

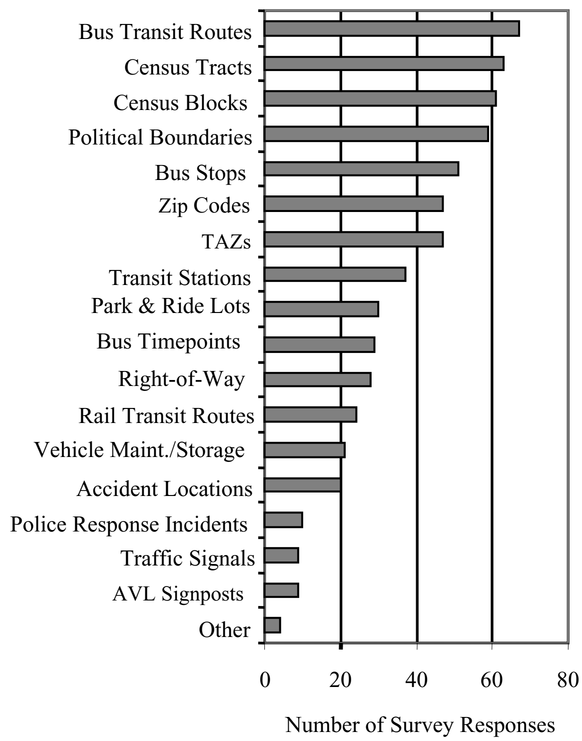

FIGURE 5 Types of transit spatial databases in 2003.

of remote sensing and spatial IT for transportation. Early on, the program, administered by the Research and Special Programs Administration, worked with the FTA to promote applications of remote sensing to transit. This seems to be succeeding based on the increase in GIS applications between 2002 and 2003; 41% and 49%, respectively. The clear trend between 2002 and 2003 is to use the locally produced aerial photography followed by the U.S. Geological Survey's digital orthoquads and state-produced digital orthophotos. The commercial satellite business has begun to penetrate the transit market, even among the small- and medium-sized properties represented in the survey.

Integration of Location Data from GPS

The 1990s witnessed a major increase in the application of GPS within the transit industry. There appears to be several reasons for this development. First, a significant number of transit systems deployed AVL systems as developed by a number of vendors that often used GIS software to display the location data. Second, with the decision of the U.S. Department of Defense to stop introducing errors in the GPS signals available for civilian use (called Selective Availability) coupled with the declining cost of GPS receivers, GPS became the method of choice to locate geographic assets, such as bus stops and other amenities. GIS vendors and GPS manufacturers were quick to facilitate the downloading of geographic data from GPS receivers into desktop GIS software for spatial analysis. The result was the creation of unique geographic databases that could be readily updated in real time. GPS use was recorded in 52% of the 2003 survey respondents.

Future Use of GIS

The 2002 and 2003 surveys addressed the future use of geospatial data and analysis in transit by asking respondents which areas they would like to use GIS in addition to their current use. The most frequent response was the customer-oriented interactive travel planner application followed by the traditional areas of GIS applications, namely, service planning (including paratransit and FTA policy areas) and map products. Displaying and analyzing AVL data is tied with police operations, including criminal investigation, accident/incident investigation, security and counterterrorism, as the next most wanted applications.

Comparing the 2003 current use GIS applications to the future use for the same categories indicates the most likely areas to see GIS deployment in the future (Figure 6). For example, in 2003 the two largest current uses were service planning and map products, with more than half of the respondents reporting the use of GIS in these activities. These two categories were also among the highest responses

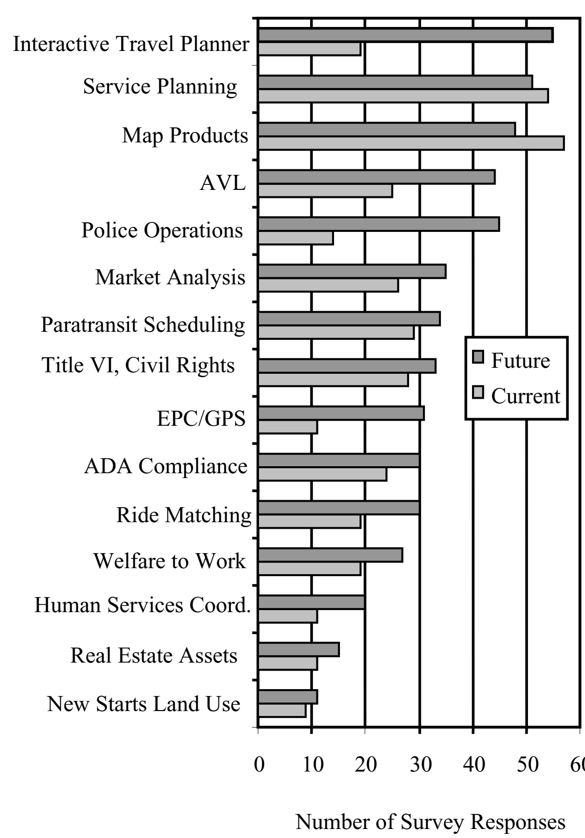

FIGURE 6 Current and future use: 2003 GIS survey.

in the future category. Apparently, nearly every respondent who is not doing service planning or creating map products using GIS wants to. The next striking pattern is the disparity between GIS users who are not currently using GIS in a particular specialized GIS application category, but report that they want to in the future. Most of these "would like to" areas relate to deployment of geospatial data collection and ITS components, including interactive travel planning, AVL, electronic fare payment using GPS data collection, and HST coordination using geospatial data collection and analysis. It is noteworthy that the transit police operations show a desire to use geospatial tools.

SUMMARY OF SURVEY FINDINGS

The 2002 and 2003 surveys used state-of-the-art web survey instrument and database software designed to make the survey easy to use for transit industry responders. In both surveys, transit authorities and planning organizations with small- and middle-sized operations responded to these features. Larger transit properties and planning agencies were not responsive when compared with the results of surveys of the 1990s. In the latter surveys, FTA support contractors individually called the organizations and conducted the survey over the telephone. Although this was less efficient and beyond the resources of the 2002 and 2003 surveys it may have been more effective in gaining more responses from the transit industry. With this caveat, the 2003 survey attracted more than 100 responses and provided some useful insights into current and future practices.

The features of GIS and GPS that have been so successful in business and government are also successful deployments in transit, including

- Visualization and presentation of spatial phenomena (e.g., routes/stops and community demographics),
- Integration of geographic data from diverse sources based on geographic location, and
- Analysis of location considerations for market analysis and customer service.

Integration of data from GPS for vehicle location and location of assets (stops, routes, rights-of-way) into GIS for display and analysis has been embraced by the transit industry as GPS receivers and GIS software has become less expensive and easier to use. Moving GIS to the Internet for customer information is identified as a future consideration for many agencies and a current practice for some. Integration of remotely sensed imagery is increasingly useful to transit applications. In particular, imagery is available to transit and planning agencies at little or no cost through local, state, and federal government sources. The integration of all three technologies: remote sensing, GPS, and GIS is becoming a very valuable tool for analysis and presentation to transit decision makers. In addition to spatial resolution, the enhanced temporal resolution (timeliness) inherent in these technologies is of particular relevance to transportation analysis and customer service improvements.

The contributions of geospatial information systems and analysis to federal programs, policies, and regulations are significant and apparently increasing in applications from 2002 to 2003. In order of frequency they are Title VI (Civil Rights) compliance, ADA compliance, Welfare to Work planning and operations, HST coordination, and New (Rail Transit) Starts land use supporting analysis. The relationship of geospatial information systems as the underlying technology for ITS is readily apparent in the current and future areas of applications in paratransit scheduling, AVL systems, on-board collection of electronic fare systems with GPS, and ride matching.

Finally, in view of the role of GPS, remote sensing and GIS in law enforcement and homeland security, the increase in responses to current and future applications in accident/incident investigation, criminal investigation, security, and counterterrorism from 2002 to 2003 may be significant.

CHAPTER FOUR

GENERAL CASE STUDIES SURVEY RESULTS

INTRODUCTION

To balance the findings of the 2002 and 2003 transit GIS surveys, which collected information from mainly small- and medium-sized transit agencies, case studies were conducted with the following large transit agencies:

- Chicago Transit Authority (CTA),
- King County Metro Transit,
- Miami–Dade Transit (MDT),
- New Jersey Transit (NJ Transit), and
- TriMet (Portland, Oregon).

The five case study sites are considered a representative sample of large transit operators in the United States. They are also known to have active GIS programs, including some innovative projects, which makes them attractive case studies to discover leading edge examples of the use of GIS. The case studies were conducted on site with the GIS program managers and other staff (technical and managerial), preceded by a questionnaire to gather some basic information on the agency and its GIS programs. The format of the questionnaire followed a format similar to the 2002 and 2003 GIS surveys with some minor modifications, which allows for comparison with the small- and medium-sized transit agencies.

This chapter begins with a summary of the results of the survey that provides an overview of the status of their GIS programs. These findings are then compared with the results of the 2002 and 2003 surveys and some general conclusions are drawn on the implementation of GIS programs in different sized agencies. This is followed by the five case studies, which provide additional information that is used to evaluate the state of the practice in leading edge agencies.

SYNTHESIS CASE STUDIES

The survey gathered information on GIS services, applications, data (including data sources, digital centerline files, and images), use of related technologies such as GPS, users within the organizations, and how the GIS program is managed. A copy of the questionnaire is included in Appendix A. The findings are presented here.

Agency Size and Service Area

The case study agencies are among the largest and most complex in the United States, offering rail, light-rail, and paratransit services in addition to the traditional bus services, as shown by the data in Tables 4 and 5. The data show the extent of their operations and the number of transit features that they have to manage including bus routes, bus stops, and vehicles.

Current GIS Programs

The case study agencies are all major users of GIS in a wide variety of business applications (Table 6). There is an example of GIS use in nearly all application areas with the exception of kiosk-based itinerary planning, smart cards for transit passenger data collection, and counterterrorism. It's not surprising that kiosk-based applications are not mentioned, as these have been superseded somewhat by the Internet. The most popular uses of GIS are in service planning, map production, market analysis, paratransit scheduling and dispatch, ADA compliance, Title VI programs, and AVL applications. There is a move away from traditional areas into new applications in operations and trip planning. Comparing the results to the small- and medium-sized

TABLE 4
GENERAL INFORMATION ON CASE STUDY AGENCIES' SIZE AND SERVICE AREA

Agency	No. of Counties in Service Area	No. of Cities in Service Area	Service Area (square miles)	Service Area Population
TriMet	3	27	574	1,300,000
King County Metro Transit	1	39	2,128	1,800,000
NJ Transit	28	NJ statewide, New York City, Philadelphia, Wilmington, some surrounding counties in NY and PA	7,500	8,400,000
Miami–Dade Transit	1	33	285	2,200,000
Chicago Transit Authority	1	43	275	3,403,415

TABLE 5
TRANSIT OPERATING STATISTICS OF CASE STUDY AGENCIES

Agency	Size of Fixed-Route Bus Fleet	Annual Revenue Vehicle Miles (millions)	No. of Routes	No. of Stops	Annual Passenger Trips (millions)	Size of Paratransit Bus Fleet	Size of Rail/Light-Rail Fleet
TriMet	655	23.8 bus 3.2 rail	100	8,100	88.9	203	78
King County Metro Transit	1,203	42.5	232	9,596	95.3	287	0
NJ Transit	2,027	66.8	274 bus 12 commuter rail 3 light rail	17,000	138.9 bus	192	711 45 LRV
Miami–Dade Transit	792	31.7	93	8,800	85.6	N/A	148
Chicago Transit Authority	2,000	N/A	148	12,463	457.2	N/A	1,190

Notes: N/A = not available; LRV = light-rail vehicle.

agencies reported in chapter three (Tables 1–3), the uses of GIS are similar, albeit in the larger agencies there is more use of GIS generally, which is to be expected given their size and operational capacity. Interestingly, when asked about their future uses of GIS (see Figure 6), the 2003 survey respondents mention those application areas that the larger agencies are pioneering, including interactive trip planning, AVL, and police operations. Transit agencies are realizing that these application areas are critical and new technologies enable their development even in small- and medium-size agencies.

One area where agencies differ is in their use of contractors to assist in the GIS programs. There are notable differences in the areas of applications development (Figure 7) and training (Figure 8). Some agencies prefer to internalize

TABLE 6
CASE STUDIES: GIS APPLICATION AREAS

Application	TriMet	King County Transit	NJ Transit	Miami–Dade Transit	Chicago Transit Authority
Service Planning	x	x	x	x	x
Market Analysis	x	x	x		x
Map Production Design and Publishing	x	x	x	x	x
Fixed-Route Scheduling	x			x	
Interactive Itinerary Travel	x	x			
Kiosk based					
Internet based	x	x	x		
Ride Matching	x	x			
Transit Pass Use					x
Turnstile/platform data collection					x
Onboard vehicle data collection with GPS			x	x	x
APC	x	x	x		x
Smart card					
Display of AVL	x	x		x	x
Real-Time Bus Display		x		x	
Paratransit Scheduling and Dispatching	x	x	x		x
Real Estate Asset Management	x				x
Police Operations					
Security	x	x			
Criminal investigation	x		x		
Counterterrorism					
Accident incident reconstruction	x	x			x
ADA Compliance	x	x	x	x	x
Title VI of Civil Rights Act	x	x	x		x
Welfare to Work		x			x
Human Services		x			
New Starts Supporting Land Criteria		x	x		x
Other (specify)					
Real-time bus display	x				

Notes: APC = automated passenger counting; AVL = automatic vehicle location; ADA = Americans with Disabilities Act.

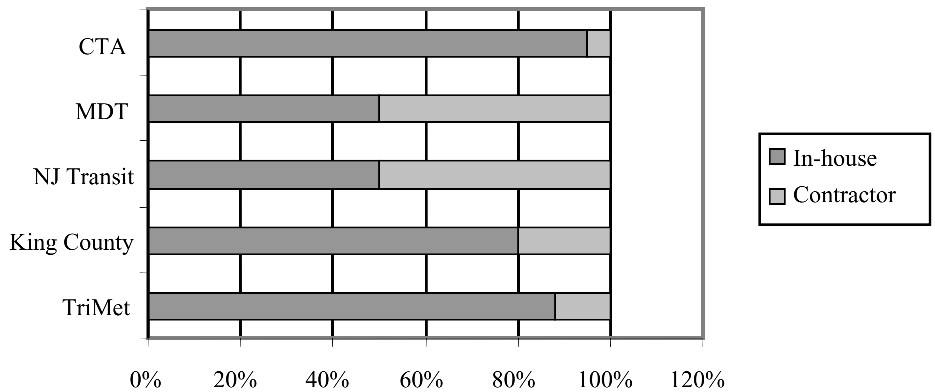

FIGURE 7 Case studies: GIS applications development.

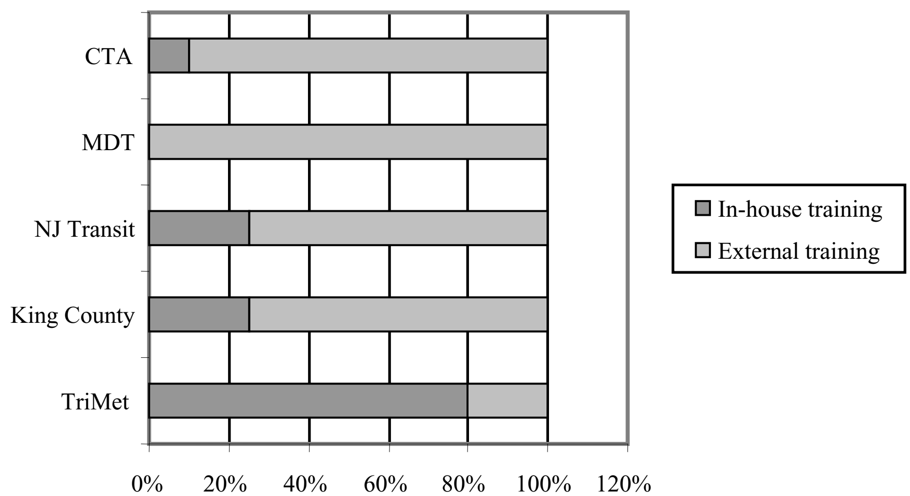

FIGURE 8 Case studies: GIS training programs.

all GIS development, whereas others prefer to use a mixture of in-house resources and external contractors. In data collection, map production, and technical support/systems integration, the large agencies mostly preferred in-house development over external contractors, with the exception of CTA, which uses a mixture of contractors and in-house staff for data collection and technical support/systems integration. The use of external training is related to the types of training programs; that is, basic user training vis-à-vis more specialized GIS programs. Some agencies such as TriMet provide in-house training to their users and use external contractors for specialist training. Others, including MDT and CTA, rely much more on external contractors or other agencies to provide training to both users and GIS specialists.

GIS Software

The number of software licenses in each agency is listed in Table 7. Most agencies use more than one GIS platform. This is reflective of a trend in nontransit agencies, such as state DOTs and may be attributed to the increasing interoperability of GIS software, thus lessening dependence on a single vendor, or that the wider use of GIS in transit agencies means that there is more opportunity to use multiple platforms.

Non-GIS Software

The survey of larger transit agencies included a question on their use of non-GIS software in the different business areas. This is of interest to GIS managers as these programs are spatial and temporal in nature; however, traditionally they have not included GIS or mapping capabilities. Examples include programs for trip itinerary planning; scheduling, including paratransit services; ride matching; and AVL applications. A listing of the non-GIS transit software in the five case study sites is shown in Appendix D.

Recently, these agencies have been developing their own GIS interfaces or creating routines to export their data into

TABLE 7
CASE STUDIES: GIS PLATFORMS AND NUMBER OF LICENSES

GIS Software	TriMet	King County Metro Transit	NJ Transit	Miami–Dade Transit	Chicago Transit Authority
ArcView 3.x	25	20		12	31
ArcView 8.x	25	5		1	31
Arc/Info	5	4			2
MapObjects	Site license	4			
MapInfo	2		2	2	
Autodesk Map	2	1			
Geomedia			12		
Intergraph MGE			10		
TransCAD			2	1	1
Oracle Spatial			12		1
Other	ArcIMS, ArcSDE	ArcSDE	Geomedia Web	MA/COM CAD/AVL	ArcSDE, ArcIMS

a compatible GIS format such as shapefiles. Even so, the way the data are specified may still make it difficult to integrate with the base map or other transit data managed in the GIS. The interviews with the GIS staff revealed some of these frustrations: although GIS software is becoming more open and compatible with data exchange standards, the traditional programs for transit operations remain largely closed and proprietary. The survey revealed only a few vendors in the transit software market for scheduling, paratransit, and trip itinerary planning products. A survey by the *Urban Transportation Monitor* in 2002 confirms this situation in the North American market (*44*). There is a similar situation in the AVL marketplace. This dominance of transit software by a small number of companies lowers competition and encourages the continuation of proprietary software and data formats. The transit agencies would prefer more open standards that allow for a modular approach to software integration between different products.

Some transit agencies prefer to implement programs from a single vendor, whereas others like to use multiple vendors. The areas in which these programs operate overlap with GIS programs, which is the cause of some of the complexities in converting data between the different formats. There is not necessarily a conflict between these programs, and some agencies have worked out procedures to overcome these problems through data import/export. This is not the ideal approach, and having data in multiple formats inevitably complicates business processes and results in data redundancy and duplication. This issue appears to be a significant barrier to accomplishing enterprise GIS in transit. Standards may address some of these issues; however, this is clearly an issue of concern to transit agencies and could be an area for further research.

Street Centerline Data

A critical piece of the GIS infrastructure is the source and maintenance of the street centerline network. With the exception of NJ Transit, all the other agencies use centerlines created in the public sector and maintained by themselves or in collaboration with public agencies (Table 8).

This is a significant contrast with the small- and medium-sized transit agencies that rely much more on TIGER files and other local government sources that are updated much less frequently. One of the noticeable features of the larger agencies is their focus on data accuracy to support operations as well as planning functions. In a large transit agency, bus stop locations and routes can change daily so that the centerline files need to be accurate enough to geo-

TABLE 8
CASE STUDIES: STREET CENTERLINE DATA

Agency	Primary Street Centerline File	Other Street Centerline Files	Update Cycle	Maintained in GIS
TriMet	Regional/Portland MPO	N/A	Quarterly	Yes
King County Metro Transit	King County	N/A	Daily	Yes
NJ Transit	NAVTEQ		Twice per year	Yes
Miami–Dade Transit	Miami–Dade County	GDT, TIGER	Daily (county)	Yes (county)
Chicago Transit Authority	City/county	TeleAtlas (for paratransit)	Weekly	Yes

Notes: N/A = not available; MPO = metropolitan planning organization; TIGER = Topologically Integrated and Geographic Encoded Reference System; GDT = Geographic Data Technology.

TABLE 9
CASE STUDIES: USE OF REMOTELY SENSED IMAGES

Agency	Aerial Photography	Source	How Often Is it Purchased?	Level of Accuracy/ Resolution (pixel size)	Cost	No. of Images
TriMet	Eight-bit color orthophoto images, variety of formats	Regional photo consortium	Annually	6-in., 1, 2, 4,10, and 20 ft	$23/ section	564 sections
King County Metro Transit	King County	KC roads	As needed	10 ft	N/A	N/A
NJ Transit	USGS—State Partner Program 2002, funded through state/federal partnership, actual contribution of agency was approximately $75,000	USGS	5 yr	1 ft pixel	>$1.5 million	>1,000
Miami–Dade Transit	County GIS maintained	Woolpert	Biannually	3 in.	N/A	N/A
Chicago Transit Authority	City of Chicago (color), Cook County (black and white)	City/county, by agreement	2 yr	6 in.	0	1,187 city, 4,486 county

Notes: N/A = not available; USGS = U.S. Geological Survey.

code changes in location and current enough to include subdivisions and new developments that opened in the past year. Many agencies are looking forward to real-time data updates of their centerline data.

Remote Sensed Images

Similar to the 2002 and 2003 survey results, the case study agencies make widespread use of satellite images, aerial photographs, and LIDAR images (Table 9). The cost of acquiring these images has fallen in the past few years, and GIS software provides better tools for integrating images into their databases. In many cases, the images are acquired through a local consortium or in partnership with the county or state. Images are very effective data sources for improving transit data and reviewing the quality of data acquired from other sources. The accuracy, quality, and multispectral scope of the images have improved dramatically in the past few years and the current generation of satellites is having a major impact on transportation data sources. There are even experiments to use unmanned aerial vehicles that can hover over roads and provide real-time data streams, including images, on traffic conditions and incidents. This is a rich area for research. The increasing use of cameras and road sensors to monitor traffic may also have applications in transit, security, and fleet monitoring. There are some privacy concerns with the deployment of surveillance equipment and there are also concerns about the access to data that might be used by terrorists. These concerns need to be balanced against the benefits of more real-time information in transit management and customer service, another suggested area for further research.

Web–GIS Applications

Somewhat surprising is the relatively low level of use of Internet Map Servers (IMS) in delivering web–GIS services to internal and external customers (Table 10). This may be because of some limitations of IMS technology or it may reflect concerns about data security and access through the agency's firewall. Web–GIS services were omitted from the 2002 and 2003 surveys; therefore, it is difficult to draw any conclusions from the comparison with small- and medium-sized agencies. Compared with other transportation agencies, such as the state DOTs, transit's use of web–GIS services appears to be lagging. There are many examples of successful web-based GIS programs for serving maps and geographic data over the Internet, and several deployments allow data editing and analysis in addition to map display and query tools. As mentioned in the literature review, web–GIS is making rapid advances with emerging standards for data exchange. This would appear to be an area ripe for GIS applications such as trip planning and AVL. Some of these applications are present in the case study sites, but presently only at a rudimentary level. The relatively low level of deployment of web–GIS services may indicate less need to interface with external customers. It may also reflect some concerns with the capabilities of IMS programs, which are still in their early stages of development.

IT Infrastructure

Table 11 summarizes the main components of the GIS/IT infrastructure. All the agencies use Windows operating sys-

TABLE 10
CASE STUDIES: WEB–GIS SERVICES

Agency	Internal Map Server Software	Used to Access GIS Data	Used to Access GIS Applications?	Provides Real-Time Bus Location Information	Map Server for External Customers
TriMet	ArcIMS	Yes	No	Yes	Yes
King County Metro Transit	Built by UW transportation engineering department	Yes	No	Yes	No
NJ Transit	GeoMedia Web	Yes	Yes	Yes (train only)	No
Miami–Dade Transit	ArcIMS	No	No	Yes	No
Chicago Transit Authority	ArcIMS 4.0	Yes	Yes	Yes	No

Note: UW = University of Washington.

TABLE 11
CASE STUDIES: IT INFRASTRUCTURE FOR GIS PROGRAM

Agency	Agency RDBMS	Server Operating System	Client Operating System
TriMet	Oracle	Linux & Unix	Windows
King County Metro Transit	Oracle	Unix TTM64, Windows 2003	Windows 2000, XP
NJ Transit	Oracle/Oracle Spatial	Windows 2000	Windows 2000
Miami–Dade Transit	Oracle/SQL server	Windows 2000	Windows XP
Chicago Transit Authority	Oracle	Sun OS	Windows NT/2000/XP

Note: RDBMS = Relational Database Management System.

tems on the client desktop computers. Windows is also used on the servers and two agencies, NJ Transit and MDT, are Windows-only agencies. The others maintain a mixture of Unix and Windows servers, with the exception of TriMet, which has opted to implement Unix and Linux servers. The other major component of the IT infrastructure is the DBMS, and in all five agencies Oracle DBMS is used.

Human Resources

The survey asked questions on the staffing and budgets for the GIS program (Figure 9). The differences in the level of GIS staffing is less related to agency size and more to operating practices. Consequently, the number of dedicated GIS staff is only one indicator of the level of GIS activity in the agency. For example, CTA has a large number of users even though it has a relatively small pool of dedicated GIS staff. With this caveat in mind, some general observations can be made. First, four of the five agencies appear to have a dedicated pool of staff resources to support the GIS program, supplemented by contractors where funding is available. In Miami–Dade County, contractors are used more than in other agencies (see Figures 7 and 8). Second, the role of the GIS staff is changing from providing general support functions (maps and spatial analyses) to providing more specialist programming and applications development. In some agencies, such as NJ Transit, users are being encouraged to make their own maps and perform their own analyses following some limited GIS training, rather than rely on the central GIS unit. Third, in some cases, transit agency staff can call on GIS support from the county or other local government where these arrangements exist. Otherwise, the GIS units operate independently within the prevailing organizational structure. Further comment on this issue is made in the individual case studies.

During the on-site visits, most agencies indicated that there were insufficient resources to support the GIS program in terms of staffing and the staff skill requirements for an appropriate GIS program. In comparison with the small- and medium-sized agencies, the large agencies are better staffed, especially if they have access to a larger pool of GIS and IT staff. It should be noted, however, that other than dedicated staff there are many GIS users in transit agencies. Figure 9 shows the range of dedicated GIS staff in the five agencies. Most have a mixture of manager, programmer, analyst, and technician positions, although some of these are shared with IT or other departments. Smaller agencies have difficulty in gathering a broad pool of resources, as described earlier in the GIS survey. In their case, they either have to limit their GIS programs or rely more on the users to perform the GIS functions. The user base is growing over time and some functions that were previously undertaken by specialist staff can now be done by users. The GIS staff is more directed toward managing the infrastructure and custom applications development rather than routine functions.

There appears to be a trend toward locating the GIS units in the IT department, which allows resources to be

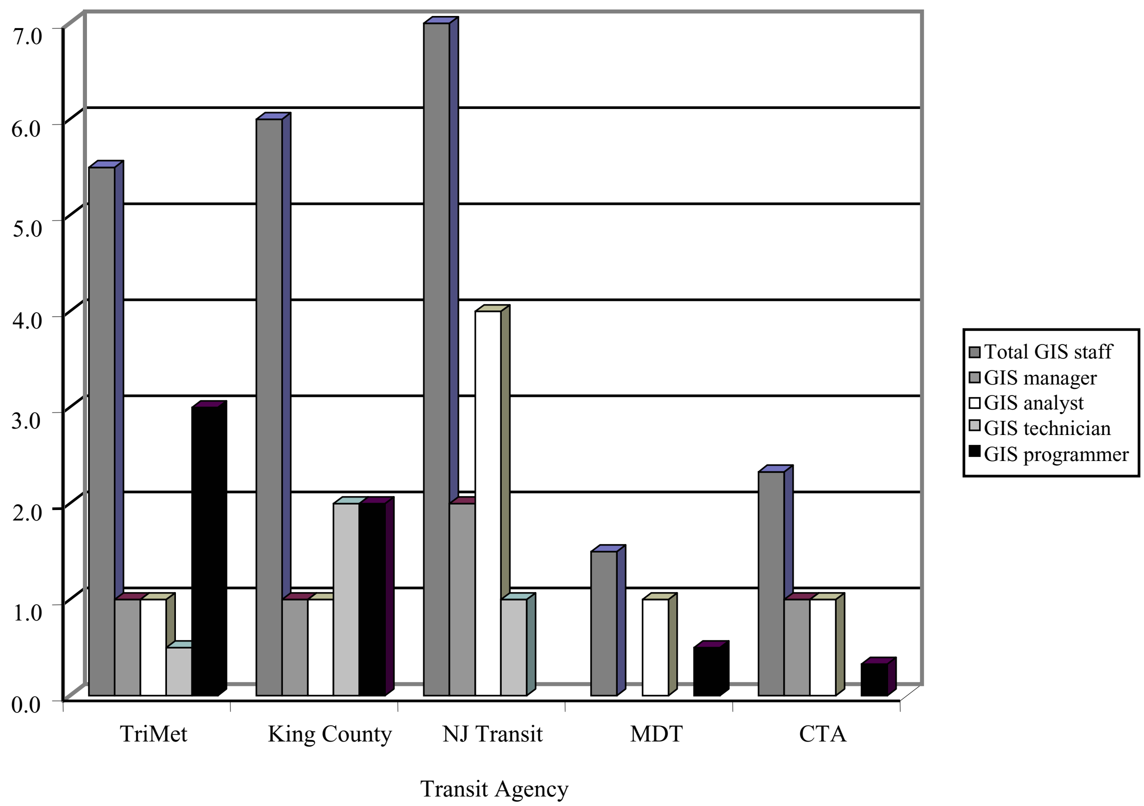

FIGURE 9 Case studies: GIS staff resources.

shared. This can also benefit professional development of the GIS staff, especially if they are graded as IT professionals. There are other opportunities for professional development through partnerships with universities and other agencies in developing GIS programs, pursuing research, and so forth. MDT and CTA have collaborative arrangements with universities. These generalizations are subject to a number of caveats that are explored in the individual case studies.

GIS Budgets

The survey included questions on the budgets for the GIS programs. The answers to this question were somewhat ambiguous and in some cases made interpretation difficult. GIS budgets include staff, contractors, equipment, data, and special projects, which may fall under different programs in each agency, making it difficult to identify all the costs under a single GIS heading. Therefore, the results are estimates based on the responses received. The budgets range from $178,000 to $1,025,000, with an average of from $600,000 to $700,000. The purpose of this question was not so much to compare budgets between agencies but to indicate the level of resources that are typically needed to operate more enterprise GIS programs. The estimates vary somewhat and no doubt reflect the approach to managing the GIS program. At a minimum, they show that operating a GIS unit requires a level of resources commensurate with its mission, and given the size of some of the GIS programs they may justify being set-up as a separate cost center with their own budgets (this may already be the case in some agencies). This is an area that could benefit from further study.

Location Within the Organization

As the GIS units develop and grow, their location within the organizational structure becomes more of an issue. This issue appears to cause some anxiety among the GIS managers. The general consensus is that moving GIS into the IT division is a good move for the GIS program and for the staff members. This trend is apparent in the case study agencies (Table 12). GIS programs that remain in planning seem to grow less than those that are part of IT. Perhaps this is because IT has more budget and discretionary spending on IT programs, or possibly because GIS and IT fit together better than GIS and planning. As described in chapter one, GIS is becoming more “IS” and less “G,” and converging with mainstream IT, in which case the integration of GIS in the IT department seems sound. The corollary argument is that the emphasis on methods and technology moves GIS away from the domains of transit

TABLE 12
CASE STUDIES: ORGANIZATIONAL LOCATION OF GIS PROGRAM

Agency	Department
TriMet	GIS section in IT division
King County Metro Transit	Distributed GIS within county
NJ Transit	GIS unit within planning department, DBA within IT department
Miami–Dade Transit	Information technology services
Chicago Transit Authority	Data services and technology development

Note: DBA = database administrator.

practice, such as scheduling and planning. There are some concerns that if GIS becomes a back office IT activity it will evolve into just another information system. Aficionados of GIS often cite it as being a different type of IT, more strongly rooted in a discipline—geography—with special capabilities to manage spatial data. Therefore, the dilemma that some of the large transit agencies face is that having grown up and matured, now what do they want to be? This is a dilemma shared by other transportation agencies, not just transit.

CHAPTER FIVE

CASE STUDIES OF GEOGRAPHIC INFORMATION SYSTEM IMPLEMENTATIONS IN LARGE TRANSIT AGENCIES

This section describes the implementation of GIS in each of the five transit agencies visited for the case studies. Each case study describes the GIS program in terms of organization, geospatial data management, linear data management, and GIS services. A summary is provided at the end of each case study and some general conclusions drawn on the agency's approach to implementing the GIS program. This information supplements the general trends highlighted in the previous chapter.

NEW JERSEY TRANSIT

Formed in 1979 following an amalgamation of several transit properties, NJ Transit is New Jersey's public transportation corporation. It is the nation's third largest provider of bus, rail, and light-rail transit, linking major points in New Jersey, New York, and Philadelphia. The agency operates a fleet of more than 2,000 buses, 700 trains, and 45 light-rail vehicles. On 236 bus routes and 11 rail lines statewide, NJ Transit provides nearly 223 million passenger trips each year. NJ Transit also administers several publicly funded transit programs for people with disabilities, senior citizens, and people living in the state's rural areas who have no other means of transportation. In addition, the agency provides support and equipment to privately owned contract bus carriers.

GIS Program Organization

NJ Transit has had a GIS program since 1990 and uses a variety of GIS platforms, although it plans on standardizing on Geomedia from Intergraph as their primary GIS program. The GIS program is one of the best staffed programs among transit agencies, with 6.5 full-time equivalent (FTE) staff. These staff possess most of the technical skills required for an enterprise GIS program. Even so, most of the GIS programming is contracted out. One staff position is funded by the rail program and is dedicated to development of rail GIS applications. In addition, database administration tasks are shared with the IT department.

The GIS program is part of the Division of Strategy, Policy, and Analysis within the Department of Policy, Technology, and Customer Service. It has its own budget and cost center. It is not a business unit under IT or Service Planning; rather, it operates somewhat independently to provide cartography, data compilation, and GIS services to other customers within the organization. The biggest current customer is paratransit, which uses GIS data and analysis to determine eligibility for special transportation services.

Geospatial Data Management

The GIS business rules and procedures have evolved to be consistent with service planning, which includes bus scheduling, bus stop maintenance, and paratransit services. The GIS databases and metadata nomenclature are related to scheduling, and the GIS program is therefore very strongly grounded in NJ Transit service planning business processes. The GIS program integrates data provided by the service planning unit, which maintains its own inventory of bus stop amenities and routes in the scheduling program. These data are exported to GIS, which maintains a comprehensive set of data, as illustrated in Table 13.

NJ Transit is different from most transit agencies in using a commercial map vendor—Navigation Technologies, Inc. (now known as NAVTEQ)—to provide and maintain the street centerline networks and attributes. The GIS group incorporates updates of the NAVTEQ data twice each year. All of NJ Transit's GIS-based applications and trip planning systems (paratransit and Advanced Traveler Information System) now reference the NAVTEQ centerlines. The trip planning systems are separate applications that interface with the GIS. In Table 13, NAVTEQ format is used to store the landmarks (points). The DGN (Design File) format refers to the spatial data file format used by Intergraph MGE, which is inherited from Microstation. The NAVTEQ centerline data are converted into DGN/Oracle format for use in Intergraph MGE. Integrating the GIS with Oracle, which is the standard in the agency, helped to establish credibility for the GIS program because the spatial and transit business data are all stored in the same format. The other point to note in NJ Transit is their use of Oracle Spatial as well as Oracle databases. Oracle Spatial is capable of storing spatial data objects as well as alphanumeric data types in its own spatial data format, referred to as Spatial Data Object Geometry [this is equivalent to the compressed binary format that ESRI use in their Spatial Data Engine (SDE) product]. Oracle Spatial manages the spatial data for the Geomedia desktop GIS applications and will be used in the future to serve data by means of the Geomedia web server. NJ Transit is in the

TABLE 13
NJ TRANSIT: SUMMARY OF GIS DATA

GIS Data	Maintained by GIS Department	Maintained by Internal Business User	Maintained by External Agency	Data Format	Database Software Used
Bus Routes	x			DGN	Oracle Spatial
Bus Stops	x			DGN	Oracle Spatial
Stop Amenities		x		Attributes of DGN	Oracle Spatial
Timepoints	x			DGN	Oracle Spatial
Transit Centers					
Park & Ride	x			DGN	N/A
Light Rail Alignment and Stops	x			DGN	Oracle Spatial
Landmarks			x	NAVTEQ	
Transit Boundary					
ADA Boundary	x			DGN	Oracle Spatial
Transit Facility Locations	x			DGN	Oracle Spatial
Traffic Signals					
TAZ Boundaries			x	DGN, TransCAD	Oracle, TransCAD
Census Data	x				
Accidents and Incidents					
Customer Complaints					
Political Boundaries			x	Census and NAVTEQ	Oracle

Notes: DGN = Design File; N/A = not available; ADA = Americans with Disabilities Act; TAZ = traffic analysis zone.

process of developing web–GIS applications. Currently, approximately 80% of the spatial data are managed in Oracle Spatial for use in Geomedia and 20% in DGN/Oracle format for use with Intergraph MGE.

Linear Data Management

NJ Transit geocodes route patterns on the centerlines with their timepoints. Routes and patterns are hard coded using Intergraph's MGE segment manager program, which allows routes to be cross referenced to centerline segments (defined as node to node). Segment manager allows timepoints and bus stops to be measured along a segment using an appropriate linearly referencing method (e.g., distance offset from node). However, at this time they are investigating standards for a linear referencing system (LRS) for the bus routes that will employ milepoint referencing (along the route). Bus stop locations are officially designated by municipal ordinance and are mapped using GPS (>3 m accuracy). All known bus stop locations, ordinanced or otherwise, are geocoded to the nearest node or intersection referencing the NAVTEQ data set for use within the trip planning application. Designation of transfer locations is done by the service planners, not the GIS staff. Intergraph is developing new linear referencing tools in Geomedia Transportation, which NJ Transit is planning to implement in 2004. Oracle Spatial also has its own LRS extension, although the GIS group has no plans to implement this, preferring the Geomedia solution.

GIS Services

The GIS group provides a broad range of services to users in different sections, including

- Bus patterns for paratransit—ADA requirements include eligibility criteria related to distance from a bus route and time of service. The Trapeze paratransit program automates the analysis; however, GIS is used to delineate the routes with 0.75-mi buffers.
- Policing use of GIS data for crime analysis and CAD.
- Synchronization of bus stop inventory changes in the GIS with the service planning database.
- Calibration of the location of data collected as part of the APC program. Currently, only a few buses have APC equipment and NJ Transit is experimenting on how to synchronize the equipment with the scheduling and trip planning programs. GIS is providing a solution based on location as recorded with GPS on the buses.
- Publication of maps—This is one of the major activities of the GIS unit. GIS, Microstation CADD, and graphics software are used to create highly attractive route maps. Many specialist maps are produced and then offered to the public as Adobe pdf illustrations over the Internet.
- Integration of aerial photographs with GIS for a number of applications including digitizing rail networks and local roads in malls, etc., which are not in the NAVTEQ database; checking the location of railroad crossings, rail alignments, and other features; and identifying staging areas for special event plans or emergency evacuation routes. NJ Transit is part of a consortium that funds and manages the acquisition of statewide aerial orthophoto images. When necessary, they also occasionally pay to acquire aerial photography in support of special projects and initiatives.
- Integration of videolog and GIS for rail planning and training purposes. The videolog data and LIDAR im-

ages of all 12 rail lines will provide a very accurate and comprehensive database of rail facilities and features. The agency is looking to develop a number of applications for maintenance and management of the rail infrastructure and to support incident response efforts with spatial data.

In addition to the GIS staff, there are approximately 10 individual users in the various business units who use Geomedia to produce their own maps and respond to simple queries. No formal training program is provided, although most new users already have some background and skills in GIS.

Summary

NJ Transit appears to have a mature and well-managed GIS program that has clear goals and a business plan to accomplish these goals. The GIS group acts as a support center that is almost transparent to business users. It is embedded in the business processes of the agency and commands support and respect from the users. The group is currently addressing a number of issues as part of the GIS development. First, the growing demands from users for map services may be difficult to meet unless the users can be persuaded to perform some of these functions themselves. The deployment of web–GIS services may also help in this respect. Second, there are a number of challenges as GIS expands into the areas of customer information and vehicle location. Third, some related challenges include broadening staff expertise into new areas, staff development, increased coordination with other departments, and management of priorities and demands.

CHICAGO TRANSIT AUTHORITY

Introduction

CTA is an independent governmental organization created by state legislation. It operates the nation's second largest public transportation system and covers the city of Chicago and 40 surrounding suburbs. On an average weekday, 1.5 million rides are taken on the CTA; approximately 1 million on the 2,000 buses that operate over 148 routes. There are more than 12,000 posted bus stops. CTA's 1,190 rapid transit cars operate over 7 routes and 222 miles of track. CTA trains provide approximately 500,000 daily customer trips and serve 144 stations.

GIS Program Organization

The CTA Data Services and Technology Development Department (DSTD) provides and maintains data and information, planning support, and management decision making. The DSTD wants to leverage existing and emerging technologies in the areas of ITS, GIS, digital imaging, and the Internet. The DSTD also provides GIS and other technical support and training for the Planning and Development Department and is currently developing an agency-wide enterprise GIS system.

The current CTA staff responsible for managing GIS projects operates out of the Data Services group of the Planning and Development Department (Figure 10). Some support is obtained from Technology Management, leveraging other technical expertise for projects such as AVL, APC, and GIS. Four key principles have been established for the development of the GIS program:

- Transit is about people, space, and time. AVL, APC, and GIS are the best available technologies for measuring, understanding, managing, and growing transit.
- AVL and APC systems require and produce ample data. Commensurate staffing, resources, and skills are required to manage and effectively use these data.
- Establishing a corporate distribution database, with GIS as a core function, is crucial to any successful systems integration.
- GIS should be administered and managed as an integrated enterprise system that serves business functions throughout CTA.

CTA's GIS program is being constructed to provide the broad range of GIS services that are provided in agencies such as TriMet and King County Metro Transit (discussed later in the chapter). Indeed, a peer-to-peer visit to these agencies in January 2003, provided the catalyst to the further development of the GIS program. The GIS was started in the Planning and Development Department, but now reaches a broader constituency of users in the agency. Management recognizes GIS as a corporate program that supports many users. Spatial data are seen as a corporate resource and the GIS program is increasingly being seen as spatial data services rather than GIS, which has a legacy technology perception.

Geospatial Data Management

The data sets currently maintained in GIS are listed in Table 14. The street centerline and other spatial data are managed by the city of Chicago, which also provides aerial photographs and demographic data. CTA is connected to the city's database and receives weekly updates of the spatial data with a major update once each month. Aerial photographs are being used to update the accuracy of the centerlines. Currently, aerial photographs are updated on a 2-year cycle. The network data sets are being enhanced to show one-way streets and other important attributes.

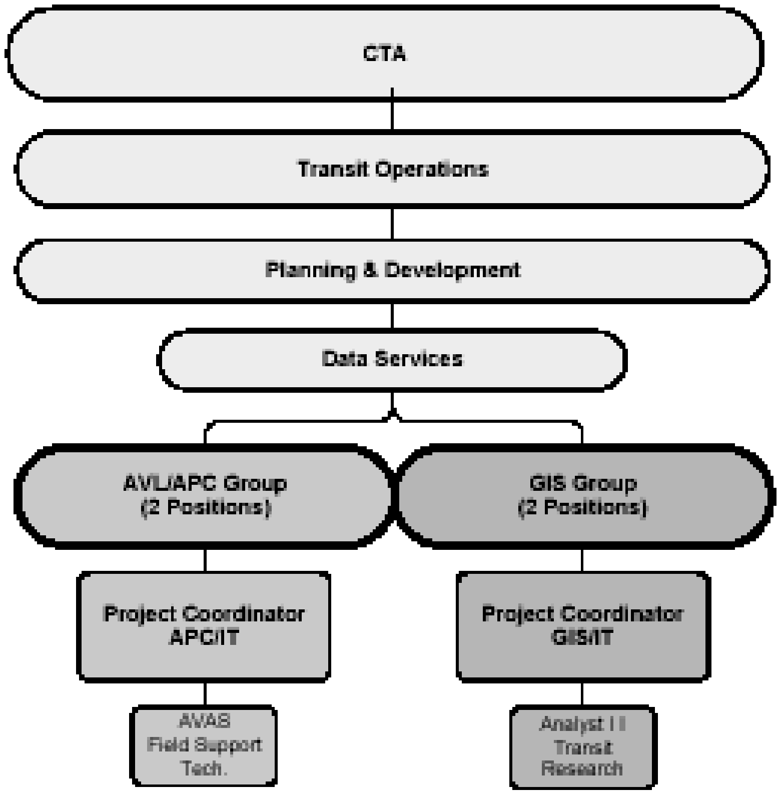

FIGURE 10 CTA data services organizational structure.

TABLE 14
CTA: SUMMARY OF GIS DATA

GIS Data	Maintained by GIS Department	Maintained by Internal Business User	Maintained by External Agency	Data Format	Database Software Used
Bus Routes	x			ESRI Geodatabase	Oracle 9i with SDE
Bus Stops	x			Geodatabase	Oracle 9i with SDE
Stop Amenities	x			Geodatabase	Oracle 9i with SDE
Timepoints	x			Geodatabase	Oracle 9i with SDE
Transit Centers	x			Geodatabase	Oracle 9i with SDE
Park & Ride	x			Geodatabase	Oracle 9i with SDE
Light Rail Alignment and Stops	x			Geodatabase	Oracle 9i with SDE
Landmarks					
Transit Boundary	x			Geodatabase	Oracle 9i with SDE
ADA Boundary	x			Geodatabase	Oracle 9i with SDE
Transit Facility Locations	x			Geodatabase	Oracle 9i with SDE
Traffic Signals			x	Shapefile	
TAZ Boundaries	x			Shapefile	
Census Data	x			Shapefile/Access	
Accidents and Incidents		x			Access
Customer Complaints		x			Access
Political Boundaries	x			Geodatabase	Oracle 9i with SDE

Notes: ADA = Americans with Disabilities Act; TAZ = traffic analysis zone; SDE = Spatial Data Engine.

The agency has good relationships with the Regional Transit Authority (which provides the trip planning program), Metra (rail), Cook County, Pace suburban transit provider, and the Chicago Area Transportation Study, which is the MPO for the Chicago region. The paratransit program uses TeleAtlas street centerlines and addresses; however, all others are using the city's spatial data.

CTA manages most of the transit data in the GIS, although some of these are duplicated from other programs such as the scheduling program and the trip itinerary planner, which are not integrated with the GIS. CTA has been focusing on building the infrastructure for the enterprise GIS and this is reflected in its use of the latest GIS software from ESRI. The data are managed primarily in Oracle with ESRI's Spatial Data Engine (SDE) providing the spatial indexing and GIS data management functions. ArcGIS 8.3 and ArcView 3.x are used for the desktop GIS. The agency has a total of 67 GIS licenses, all but one of these in ESRI products. Thus, with these data and GIS software in place, the agency is well placed to extend the GIS program to more users in the agency.

Linear Data Management

The transit routes and bus stops are being migrated to the geodatabase where they will be referenced to the centerline file as routes and events in ESRI's network model. Currently, the routes and bus stops are maintained as route-system coverage in Arc/Info and reference a legacy TIGER centerline file. Timepoints are managed in the HASTUS scheduling program and are related to bus stops and the nearest intersection. The plan is to migrate all of these data sets to the geodatabase where they can be geocoding to the city centerline file and use linear referencing methods to manage the transit data.

GIS Services

There are approximately 35 users of GIS in the various departments, including several core users in planning. There are no canned applications, but the following set of tools and programs exist to assist users in various business areas:

- Spatial Analyst extension from ESRI to perform demographic analyses and buffer analysis;
- Historical tracking of bus vehicles to analyze adherence to schedules;
- A set of tools that allow highly accurate bus stop locations to be linked to vehicle location and schedules for on-board passenger information and further development of schedule adherence;
- A major project is underway to configure GIS with AVL and APC to provide bus stop annunciation to customers. A number of benefits will occur from the integration of these systems including better customer information, monitoring of bus performance, and tracking of the vehicles; and
- Another project has created a web portal to access automated fare collection data and present it as graphs and reports that are easily downloadable for personal use and analysis. Future applications include interactive mapping using ArcIMS GIS and AVL and APC reporting.

Spatial Multimedia for Planning Support

CTA is somewhat unique in having an active program to use GIS tools as part of visual media for planning purposes. Management supports this approach and CTA has close links with the University of Illinois at Chicago, which is one of the leading centers for data visualization in urban planning. Techniques are being used to evaluate improvements to CTA's transit infrastructure and in community impact analysis of transit development in neighborhoods. The goal is to leverage technology to reshape planning at CTA, and part of this goal is to develop a spatial data infrastructure to support planning and operational activities. This involves the use of a number of innovative techniques including

- Annotation tools that enable users to "virtually draw" on an electronic map or link one's voice (or image) to an issue;
- Navigation tools that allow spatially distributed collaborators to tour and discuss sites of concern through a combination of digital video, "spatially intelligent" objects, and interactive maps; and
- Representational aids that link concrete representations, such as video or sound clips of comparable examples, to otherwise abstract output. The result is an image of a place that changes in "real time" to fit a multitude of alternative scenarios being discussed.

These may seem like abstract concepts; however, they are being developed to assist the planning process in CTA.

Summary

CTA has a mission for the GIS program that reaches beyond the traditional application areas into innovative uses for planning purposes. The agency currently is in the process of migrating its data to an enterprise GIS system and in developing applications and tools to support enterprise data management. The 2.3 FTE staff clearly has a full workload in accomplishing these tasks. They receive support from other groups in CTA including IT and appear to have embarked on a process with a clear set of goals and milestones.

MIAMI–DADE TRANSIT

Introduction

MDT, one of the largest departments of Miami–Dade County government, is responsible for planning for and providing all public transit services in the county. MDT is the 16th largest public transit system in the United States and comprises four systems—Metrobus, Metrorail, Metromover, and Paratransit. These systems combined carry nearly 300,000 passengers daily.

GIS Program Organization

The GIS program at MDT exhibits characteristics of a departmental GIS. Most of the GIS applications and the GIS software are based on ArcView 3.x desktop GIS. The GIS manager would like to migrate to the more modern GIS platform but for the cost of rewriting the scripts and tools that have been developed for the users. One possible migration path may be to piggyback on the county, which has more extensive GIS resources, including SDE and a geodatabase environment. MDT would like to migrate to a geodatabase model to manage their transit data. The two dedicated GIS staff are located in the Information Technology Services Division and are involved in GIS only 40% to 50% of their time.

Geospatial Data Management

The county maintains the street centerline file and other spatial data sets that are used by MDT. The street centerline file is an enhanced version of TIGER. The centerlines are updated daily. MDT's IT department has begun to put transit routes into the GIS and has created layers for Metrorail and Metrobus. Bus stop location data are being collected with GPS and entered into a separate database. The bus stop inventory is being driven by ADA accessibility requirements. The bus stop and transit routes can be extracted as shapefiles; they do not have any linear referencing or measures associated with them. The data layers managed by MDT are listed in Table 15.

Only a relatively few data sets are maintained in the GIS by MDT. Some of the core data, including bus routes, bus stops, and timepoints are managed by the Trapeze scheduling program, which exports the data as a shapefile. However, these data may not be referenced to the centerline file and so the data may need conflating to the centerline file. Other data sets are maintained by the county and the MPO, which use the same centerline file.

GIS Services

There are no dedicated GIS applications for planning or operations; however, there are a number of GIS tools and programs that have been developed to assist users.

- Maps of bus routes and other transit features;
- An ArcPAD application being developed to collect data at bus stops, which can then be downloaded on return to the office;
- Timepoints exported from Trapeze linked to bus stop locations;
- A work order system developed for bus stop maintenance and inventory linked to the GIS;
- AVL ad hoc reporting developed through the web and implementation of various GIS analysis and reporting applications;
- Use of aerial photographs to verify timepoints and analyze ADA requirements in light of accessibility to bus stops;
- Replacement of the MA/COM CAD/AVL systems by a more modern system that will integrate with MDT's GIS;
- A pilot project to collect APC data on two buses involved GIS in matching up the bus stops from Tra-

TABLE 15
MDT: SUMMARY OF GIS DATA

GIS Data	Maintained by GIS Department	Maintained by Internal Business User	Maintained by External Agency	Data Format	Database Software Used
Bus Routes		x		ESRI Shapefile	ArcView
Bus Stops		x		Shapefile	ArcView
Stop Amenities		x		Shapefile	ArcView
Timepoints		x		Trapeze	
Transit Centers	x			Shapefile	
Park & Ride	x			Shapefile	ArcView
Light Rail Alignment and Stops	x			Shapefile	ArcView
Landmarks	x			Shapefile	ArcView
Transit Boundary	x			Shapefile	ArcView
ADA Boundary					
Transit Facility Locations	x			Shapefile	ArcView
Traffic Signals			x		
TAZ Boundaries			x		
Census Data			x		
Accidents and Incidents		x		CAD/AVL	
Customer Complaints					
Political Boundaries			x		

Notes: ADA = Americans with Disabilities Act; TAZ = traffic analysis zone; CAD = computer-aided dispatch; AVL = automatic vehicle location.

peze with their geographic location so that ridership analysis by bus stop could be performed; and

- An IT strategic plan for MDT that suggests development of an enterprise database in Oracle that would support the creation of a geodatabase, which is the direction that the GIS staff would like to go.

Summary

MDT has a GIS program that is representative of the state of the practice among transit agencies. Even so, the GIS staff in MDT recognize the limitations of the current program and are progressing steadily toward their goal of improving transit service through the use of GIS. They work closely with the county and the MPO, who manage the spatial data and have active GIS programs. They staff is currently looking to develop the GIS as part of an agency IT plan.

KING COUNTY METRO TRANSIT

Introduction

Metro Transit refers to the public transit agency serving King County. Metro Transit operates a fleet of approximately 1,300 vehicles—including buses, electric trolleys, and street cars—that carry more than 100 million passengers annually. The agency is also well known for its use of advanced technologies and innovative practices, and the GIS program is a good example of this.

GIS Program Organization

Metro Transit has long been recognized as one of the leading agencies in applying GIS. Indeed, before GIS was popularized by the vendors, Metro Transit had developed its own home-grown GIS called TransGeo. This program was eventually replaced by ESRI software and since then the agency has reengineered its GIS program to match user needs and lay the foundation for future expansion. Metro Transit's GIS program is linked to the King County GIS Center, created in 2001 under the auspices of the county Department of Natural Resources. This reorganization was prompted in part by the desire for more accountability in the GIS program. With Metro Transit's reputation and experience in GIS, it was no surprise that the agency has become responsible for managing the transportation layer for the county—all modes not just transit—and is implementing this effort through a new project initiative called TNET (Transportation Network). The King County GIS's role is to provide coordination and oversight of the GIS programs, although GIS programs are actually largely independent.

Geospatial Data Management

Metro Transit coordinates its data management responsibilities with the King County GIS, which is responsible for collating and integrating all the data layers from the member agencies. The King County GIS in effect serves as a data clearinghouse and provides daily updates of spatial and attribute data as these are added to the database. Metro Transit has six GIS staff to support the GIS program, but it would be difficult to manage all the changes in the transportation layer on their own. The users participate in updating the transportation data, which is then checked by Metro Transit before uploading to the King County GIS. The process is shown in Figure 11.

Briefly, the consortium partner makes edits to their data on the latest version of the TNET data, which is downloaded to their local computing environment. Once they have completed the edits, the file is sent back to the TNET central data repository for quality assurance and quality control. The data are uploaded to the central repository using Go Synch! Software, which as the name implies is a program that synchronizes updates in GIS data formatted in ESRI compatible formats. This requires that the data editor use ESRI software. Once the quality assurance and quality control is complete, the TNET database updates the King County GIS data library nightly. The King County GIS publishes the daily updates by means of the Internet and produces a complete data set on CD-ROMs every quarter. The TNET system is unique in transit for two reasons: (1) it uses state-of-the-art GIS and IT technology, including web-based services and (2) the consortium to build and maintain the data consists of local cities and adjacent counties that hitherto have been reluctant to participate in data sharing arrangements. The TNET program has succeeded in overcoming both technical challenges and organizational constraints. The TNET program is a case study on its own and it is difficult to do it justice as part of a synthesis report. Additional details are available on the Metro Transit website, http://www.metrokc.gov/.

As expected, Metro Transit collects and manages most of its transit data in the GIS (Table 16). This is a very comprehensive database managed in the same GIS/DBMS format.

GIS Services

Metro Transit probably has more GIS applications in place than anyone of the other four case study agencies (see Table 6). There are two flagship GIS applications:

- An ArcView 3.x application delivered to 150 users, which is used for simple mapping, queries, and map production; and

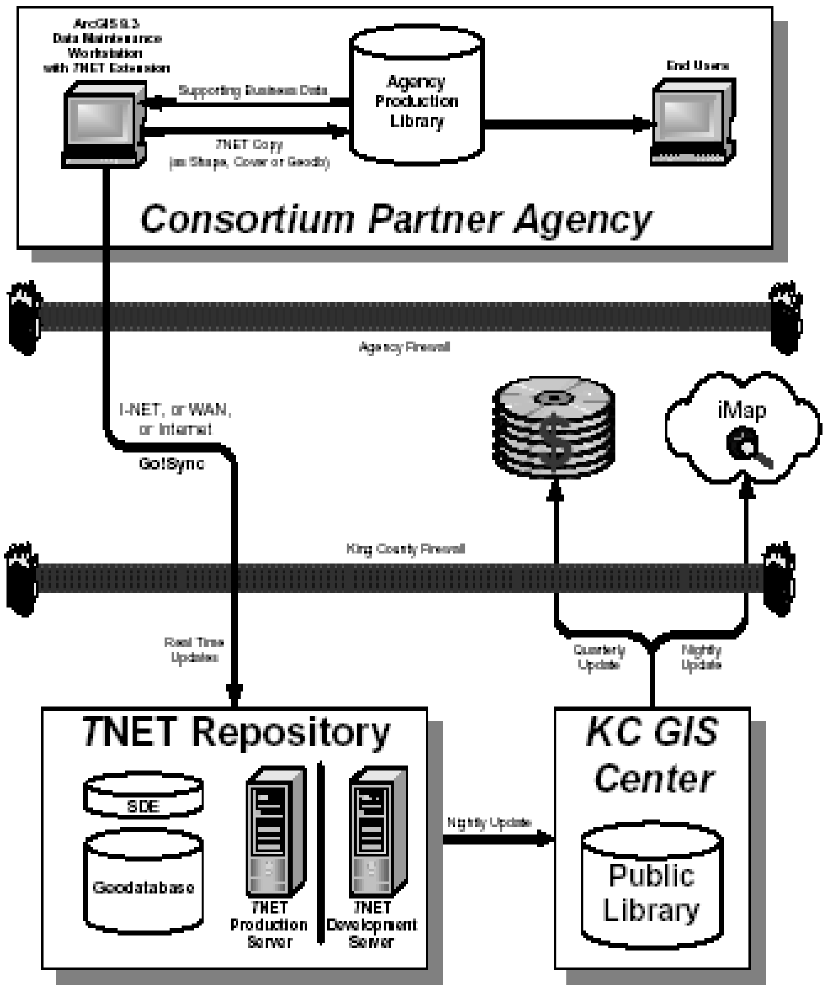

FIGURE 11 TNET: Regional data coordination system overview.

- A Transit GIS toolbox developed in MapObjects, which also is used by approximately 150 users. The transit toolbox is used to interface between the Transit Enterprise Database (TED) in Oracle and the GIS. The transit toolbox is used for bus stop data maintenance.

Metro Transit has also developed its own tools in MapObjects and Oracle to perform dynamic segmentation queries. These were developed because of the performance limitations in the Arc/Info dynamic segmentation model. Ultimately, the plan is to convert these applications to the new ArcGIS desktop environment.

The TED repository integrates data from the HASTUS scheduling together with the GIS data, which can then be made available to other users in the agency. This presents a neutral way of being able to integrate data without it being GIS or proprietary program centric. The scheduling program uses its own GIS module. Likewise, the trip planning program can import shapefiles from TED, which it then turns into MapInfo format files for use with the trip planning program. Thus, even in an advanced enterprise GIS system like Metro Transit, there are islands of data and applications that are not part of the enterprise solution, a common issue among transit agencies.

Metro Transit is currently developing a number of GIS tools for data maintenance as well as implementing a geodatabase model to manage TNET. There are several projects that are in progress and that form part of the GIS strategic and business plan for 2004. One of these is the replacement of the home-grown AVL system with a new GPS-based system that will be linked to the GIS.

Summary

Metro Transit is implementing a number of leading edge GIS applications in transit, as well as taking a lead role in

TABLE 16
METRO TRANSIT: SUMMARY OF GIS DATA

GIS Data	Maintained by GIS Department	Maintained by Internal Business User	Maintained by External Agency	Data Format	Database Software Used
Bus Routes	x	x		Arc/Info Coverage	Info/Shapefile/Oracle
Bus Stops	x	x		Arc/Info Coverage	Info/Shapefile/Oracle
Stop Amenities	x	x		Arc/Info Coverage	Info/Shapefile/Oracle
Timepoints	x	x		Arc/Info Coverage	Info/Shapefile/Oracle
Transit Centers	x			Arc/Info Coverage	Info/Shapefile/Oracle
Park & Ride	x			Arc/Info Coverage	Info/Shapefile/Oracle
Light Rail Alignment and Stops			x		
Landmarks	x			Arc/Info Coverage	Info/Shapefile/Oracle
Transit Boundary	x			Arc/Info Coverage	Info/Shapefile/Oracle
ADA Boundary	x			Arc/Info Coverage	Info/Shapefile/Oracle
Transit Facility Locations	x			Arc/Info Coverage	Info/Shapefile/Oracle
Traffic Signals	x	x		Arc/Info Coverage	Info/Shapefile
TAZ Boundaries	x		x	Arc/Info Coverage	Info/Shapefile
Census Data	x		x	Arc/Info Coverage	Info/Shapefile
Accidents and Incidents	x	x		Arc/Info Coverage	Oracle
Customer Complaints		x			
Political Boundaries			x	Arc/Info Coverage	Info/Shapefile

Notes: ADA = Americans with Disabilities Act; TAZ = traffic analysis zone.

the TNET consortium. Its leadership in GIS and transit over the years is widely recognized within the industry (and one of the reasons it was selected as a case study). The results of the survey and the brief description of some of their GIS programs demonstrate the capabilities of GIS when it is provided as part of a well-thought-out program. This is not to say that the process has been without difficulty. Metro Transit has faced a number of challenges over the years and has had to convince decision makers and others of the value of GIS.

TRIMET

Introduction

TriMet is a municipal corporation that provides public transportation for much of the three counties in the Portland, Oregon, metropolitan area. TriMet operates a comprehensive transit network, including a 44-mi, 64-station Metropolitan Area Express (MAX) light-rail system, 93 bus lines, service for seniors and individuals with disabilities, and enhanced amenities and information. TriMet carries more passengers than any other U.S. transit system of its size. Ridership on buses and MAX has increased for 15 consecutive years, and averaged 286,200 daily boardings in 2003. The quality and innovation of the transit service extends into the GIS program.

GIS Program Organization

Established in 1997, the GIS section of TriMet is part of the Information Technology Division, and has 5.5 FTE staff. Since then, the program has gradually expanded as the uses of GIS in the agency have grown. Approximately 50 users have desktop GIS programs, with approximately 25 of these considered power users who use ArcGIS 8.x. The other 25 ArcView users will be migrating to customized applications for specific requirements. These customized MapObject applications will also broaden usage of GIS throughout the agency. The other users will access the GIS through the IMS. The development of the GIS program followed an analysis of user needs in the agency, and from the beginning users have been involved in steering the types of GIS applications developed. For example, early on a Bus Stop Group was formed to redefine the business process for bus stops and work orders. This led to the establishment of the Bus Stop Group as a new division tasked to manage and maintain the bus stops. One of the core applications of the GIS program is the Stop and Amenities Maintenance (SAM) application, which is tied to a SAM Work Order Tracking System (SAM-W) for automatic updates.

Geospatial Data Management

The street centerline data are acquired from Metro, the MPO in the Portland area, which has an active GIS program that maintains and integrates data for the jurisdictions in the Metro area and distributes quarterly updates to its members. The GIS section does not manage a large number of data sets in GIS (Table 17). Rather, these are maintained by the business users or Metro. TriMet is predominantly an ESRI product user for the GIS, and Oracle is the enterprise DBMS. One interesting feature of the TriMet IT architecture is the mixture of Windows, Unix, and Linux servers. IT applications are developed in Java or PowerBuilder, although the plan is to move to a pure Java programming en-

TABLE 17
TRIMET: SUMMARY OF GIS DATA

GIS Data	Maintained by GIS Department	Maintained by Internal Business User	Maintained by External Agency	Data Format	Database Software Used
Bus Routes		x		ESRI Shapefile	
Bus Stops		x		Oracle Table	Oracle
Stop Amenities		x		Oracle Table	Oracle
Timepoints		x		Oracle Table	Oracle
Transit Centers		x		Shapefile	
Park & Ride		x		Shapefile	
Light Rail Alignment and Stops	x				
Grade Crossing	x			Access Table	Access
Landmarks	x			Shapefile	
Transit Boundary	x			Shapefile	
ADA Boundary	x			Shapefile	
Transit Facility Locations	x			Shapefile	
Traffic Signals			x	Shapefile	
TAZ Boundaries			x	Shapefile	
Census Data			x	Shapefile	
Accidents and Incidents		x		Oracle Table	Oracle
Customer Complaints		x		Oracle Table	Oracle
Political Boundaries			x	Shapefile	

Notes: ADA = Americans with Disabilities Act; TAZ = traffic analysis zone.

vironment. The GIS staff includes Java and Visual Basic programmers, which is also somewhat unusual. However, TriMet are developing a number of web–GIS applications that are being coded in Java. The IT group maintains that the migration to Linux is a good business decision that has saved the agency money. TriMet has an open systems policy to applications development, which includes open architecture standards unless there is a strong case against it.

Linear Data Management

TriMet will be implementing a geodatabase model to georeferencing of the transit data to the centerline. Bus routes, stops, and timepoints will be referenced as SDE data layers with measures where appropriate using ESRI's linear referencing data tools. The agency does not have a formal LRS, but creates bus routes that have measures to linearly reference the transit data. Route topology is generated at the bus stop, timepoint, and pattern level to display the event data at different levels of granularity. The pattern and timepoint data are maintained by the scheduling program and the GIS regenerates the topology on the centerline for the different user applications.

GIS Services

The GIS and IT sections have collaborated in developing a number of applications that are available through the web–GIS browser or desktop GIS interface including the following:

- ACID (Accident and Incident Tracking System)—A mapping component (MapObjects application) for ACID (Powerbuilder application) provides the ability to view the location of the accident on a map and accurately store the coordinates of the location for analysis.
- BUDS (Bus Dispatch Mapping System Data Displayer)—Designed for historical analysis of service and stop event data. Includes reporting mechanisms for on-time performance, passenger census, ridership, and running times. Provides a map interface to perform spatial analyses.
- Interactive System Map—On-line application designed to locate specific areas in the service area, query, link to other sites, and provide detailed transit information, including aerial photography.
- Real-Time Bus Displayer—Desktop application designed to simulate the BDS to view the real-time location of a bus and display its status. It also has the ability to view more detailed information with aerial photography that has 6 in. of resolution.
- SAM—Designed to view all current information regarding a bus stop including amenities, passenger census, historic files, and photographs of shelters. It can list stops by route and direction.
- SAM-W—This system ties the stops and their amenities to the on-line tracking system.
- Transit Feature Management (TransFM)—This application, developed with ArcObjects, is designed to maintain spatial data such as stops, landmarks, and reroutes in a GIS.
- Transit Mapper—Application similar to the Interactive System Map, but designed for internal users with advanced capabilities and access to additional information.
- A GIS database that maintains grade-crossing information along the light-rail alignment for security purposes.

- A customer service information system that tracks customer complaints.

Summary

The TriMet GIS program is a successful example of an enterprise GIS system that has achieved this status following a well-planned GIS development program. Factors in its success include the hosting of the GIS in the IT department, a centralized database, support from senior management, and the use of a common base map for the region, which takes away the need for data development and maintenance. It also helps to have an architectural vision for the enterprise GIS system and a system's architect in IT who can oversee the implementation. The program has also found that using GIS as part of operations, such as AVL, helps to sell the service to the public as well as internal customers. Building the IT infrastructure for GIS is also an important resource that provides a foundation for quick applications development.

CHAPTER SIX

CONCLUSIONS

This synthesis provides a high-level overview of the state of the practice in geographic information systems (GIS) applications in transit planning and operations. GIS has become an important technology in transportation as transit agencies strive to adapt to the changing regions they serve. GIS can inform significant decisions that involve large expenditures. However, the synthesis emphasizes that one size does not fit all, as evident from the case studies, and that there are different approaches to the use of GIS. The size of the GIS program may not reflect quality or need in an agency; rather, it may be related to historical developments with respect to their GIS program. It is hoped that the insights provided in the synthesis will result in closer evaluation of GIS programs in light of GIS capabilities and the benefits these bring to transit planning and operations. The other major finding is the growing use of GIS in operational areas such as automatic vehicle location (AVL) and trip itinerary planning, which are customer-oriented and therefore at the core of the transit business. Traditionally, GIS has been used for map production or service planning functions, which are important but less critical to the day-to-day transit operations. As GIS migrates across these boundaries it is demonstrating its role as part of the enterprise information technology (IT) infrastructure, serving multiple uses within the agency, not just a few specialized areas.

These conclusions are divided into three areas, data, human capital, and tools and applications, and are summarized here.

GIS is somewhat unique in its ability to integrate spatial and attribute data. It is a powerful medium for visualizing transit information in a map format that can be easily understood by most users. The creation and maintenance of spatial data has become somewhat easier over the years. In the 1990s, the early adopters of GIS often had to digitize their own networks or work with rudimentary street centerline files from the U.S. Census Bureau. Today, transit agencies have many more options including using commercial map vendors or partnering with local governments to maintain street networks. Therefore, most transit agencies have access to good base maps for georeferencing their bus stops, routes, and other transit data. They have instigated procedures for updating their base maps, including the street networks, on a regular basis, in some cases daily, although weekly, monthly, and quarterly updates are more common. The accuracy and currency of the spatial data has encouraged more uses of GIS for display and analysis of transit operations as well as ridership patterns. Operational analyses such as AVL require real-time data integration, which is only feasible with an accurate and up-to-date base map.

Creating and maintaining inventories of bus stops, routes and patterns, and timepoints, as well as customer information such as boardings and alightings, along with demographic information, remains a significant effort. Bus routes and schedules are continuously changing and need to be reflected in the GIS, otherwise these data would soon be out of synch. Transit agencies are collecting this information through their scheduling and dispatching programs. Problems remain, however, in integrating these data with GIS, owing to the incompatibility of data formats and proprietary software. Some of these issues are being addressed by a number of standards initiatives in the transit industry. Of particular note is the Geospatial One Stop initiative sponsored by the federal government in partnership with industry and local governments, which has proposed standards for transit geospatial data exchange. The productivity of the GIS programs could increase if data were managed in a standard exchangeable format.

As GIS use moves into the operations arena, new challenges arise with integrating real-time information collected by the global positioning system. Similar challenges arise with the use of aerial/satellite images and light detection and ranging (LIDAR) images that can accurately depict transit features, including routes, bus turnouts, and bus shelters. Some transit agencies are now displaying these images on their websites as part of trip planning or bus monitoring programs. The added visualization improves user experience and customer satisfaction. These services require a level of data and systems integration that is more typical of larger agencies that have the additional resources needed to implement them. Even so, the trend among transit agencies has been for medium- and even some small-sized agencies to implement these operational systems with a mapping component.

Human capital includes hiring, training, and professional development, as well as organizational structures to support the GIS program. A GIS business organization can be categorized at three levels. First, at the *project* level, GIS is used on specific projects, such as creating an inventory of bus stops and routes that can be mapped or performing a ridership analysis of bus stop boardings and alightings. In such cases, the agency relies on one or two

GIS specialists. Second, as the GIS expands, it often develops into a *department* program, becoming part of the business plan for the department. At this level, GIS programs may include three to five specialists, with many additional users in the agency. The program acts as a support unit to users who require a variety of functions, from map production to applications development. Third, as the use of GIS among users grows within the agency, the GIS may evolve into an *enterprise* service that is mainstream to the organization and regarded as part of the core infrastructure. At this level, GIS is typically part of the IT department rather than residing in planning or another section. Four of the five case studies of large transit agencies have this organizational arrangement, although each agency is somewhat unique.

In the early years of GIS deployment, specialist staff was required to set up and use the GIS programs. Since the mid-1990s, however, with the implementation of desktop personal computers and web-based computing, GIS software has become more user friendly. Consequently, users can independently perform many mapping and query functions. Although specialist staff are still needed to develop applications and perform more specialized tasks, such as geodatabase management and systems integration, GIS has generally become a widely used technology that is part of the office suite. The trend among the larger transit agencies appears to be to create a dedicated GIS unit of 5 to 10 full-time equivalent specialists. It is also worth noting that these GIS units are managed alongside the IT infrastructure; therefore, the GIS program can call on a broader range of IT expertise. These synergies and efficiencies appear to be commonplace in the larger transit agencies. The GIS staff also benefits from being part of a larger IT department in terms of professional development and career opportunities.

Among smaller agencies, the GIS staff can sometimes feel isolated or confined to supporting a narrow area of the agencies' business. This may be related to size and resources available. However, one of the questions of the synthesis was where should GIS services be located? Is it an IT function or should it be closer to the business units such as scheduling and planning? There is no simple answer to this question, and there are successful examples of GIS implementations under a variety of organizational structures. Perhaps the most important factor is the commitment and support of the agency to the GIS program, including that from senior management. Some of the most successful programs have benefited from a GIS champion within management. As the use of GIS is now more widespread, its acceptance as a core technology in transit is almost a given, because there are many more mid-level and senior managers who have grown up with the technology and understand its uses and benefits. From this perspective, the prospects for its growth and support appear to be good.

There are a wide range of tools and applications of GIS in transit agencies that demonstrate the capabilities in planning and operations. The survey results show that the use of GIS is increasing in transit agencies of all sizes. The types of GIS applications vary depending on agency needs and goals, and in response to levels of funding and availability of other resources. It is also influenced by FTA policy and regulations, such as in Americans with Disabilities Act compliance, Title VI programs, and human services transportation. Therefore, it is not realistic for all transit agencies to develop enterprise GIS programs, and transit agencies would benefit from guidance on the level of resources needed to develop different types of applications. This synthesis did not specifically delve into this issue, although the results from the literature review, the 2003 GIS survey, and the case studies provide some indications of those programs that are more popular at different levels of GIS implementation and these may be an indicator of affordability.

The most successful programs appear to be those that engage users in designing GIS programs that meet business needs. Too often GIS is presented as a technical mapping solution when it is really a business tool like any other that can be customized to enhance specific business processes. GIS can provide a powerful visual medium to communicate information to customers and operators alike.

The convergence of GIS and mainstream IT, including the Internet and open standards, is changing the landscape for geospatial applications development. Within this specific area of transit there are opportunities to link GIS to operational programs such as AVL and trip planning in addition to the traditional areas of service planning and mapping. The expansion of GIS into some of these areas however can encroach on areas using non-GIS transit software, which raises a number of challenges for data integration (noted previously), systems integration, and realignment of business processes. There are successful projects in large agencies that demonstrate the benefits of more integrated approaches to systems integration and it is likely that this trend will continue and possibly extend into medium-sized agencies that express similar needs.

The implementation of GIS is often hindered by organizational constraints rather than technical difficulties. Chief among these is the lack of resources or management support to develop and manage GIS programs. The benefits of GIS are not widely understood or appreciated by managers, and to date the transit GIS community has not done an adequate job in articulating these benefits beyond their own agencies or peers. For example, AVL systems, which have a temporal as well as a spatial dimension, are driving change in transit organizations and require a significant role for GIS. Without GIS, many of these systems would not be able to integrate data and communicate bus information to customers. This synthesis describes several other benefits that GIS provides that apply to customers as well as to transit operators. GIS is an important resource in supporting programs to track and manage incidents, in accident analyses, customer complaints, and, last but not least, in police operations and homeland security. Although there are few security applications, the 2003 GIS survey included many responses that identified this as one area where agencies would like to deploy GIS.

Finally, collaboration between transit agencies and local governments and other partners seems to pay big dividends where working arrangements can be agreed on and followed. These benefits can accrue to small and large agencies.

Although there is broad use of GIS in transit, there are still gaps in the information available and areas worthy of further study. Some suggestions for future studies that arose during the course of this project are summarized briefly here.

- Improving communication of transit GIS programs and benefits to the transit industry and others. This could include investigation of the revival of the GIS and transit conferences, last held in 1999, as well as more regular channels and forums for exchanging information about what is happening in the transit GIS sector.
- The path of future development of GIS technology. GIS is becoming broader based in geospatial information systems that include the application of the global positioning system and the integration of remote sensing technology. How can transit benefit from these developments?
- The potential for GIS in emerging areas such as asset management and intelligent transportation systems (ITS). Transit is one of the core user services in the national ITS architecture and there are several examples of transit ITS projects including AVL. There are many applications making use of location-based services combined with wireless technology and telematics that transit can use and contribute to for the benefit of customers and managers.
- The use of GIS in historical data analysis, such as trends in automated passenger counts, boardings and alightings, and demographic analysis of transit passengers.
- The implications of data exchange standards. How will this affect data sharing and integration, data quality, and validation? There are several standards that affect transit and some confusion within the transit industry as to which standards to apply. Clarification and guidelines for standards implementation are needed.
- The convergence of IT and GIS. Specifically, the development of multimedia aids in planning and community outreach and how these can best include GIS. Maps and geographic data are visual mediums that can be included in many software programs that are not full-featured GIS. How can GIS and "GIS-lite" programs be developed to integrate multimedia capabilities?
- The impact of geospatial information systems in furthering the regulatory, program, and policy directions of the FTA.
- Are there specific metrics that can be developed to assist transit agencies in evaluating the benefits and costs of GIS programs? Often the costs and benefits of GIS are hidden and difficult to define within budgets and organizational arrangements. Even so, the growth of GIS and its significant cost justifies more examination of its financing and economic impacts. These audits could include evaluation of the externalities that proponents of GIS often claim arise from GIS programs.
- The role of geospatial data collection and analysis in intelligence analysis and criminal investigation. The 2003 survey shows an increasing use of GIS in transit police operations, including security and counterterrorism. This trend could be an indicator of an emerging contribution by geospatial information collection and analysis to the nation's homeland security effort.

This synthesis illustrates that there is a great deal of activity in GIS applications in transit operations and planning. It also identifies a number of gaps in our knowledge and information sharing from which the transit community and its customers would benefit. There is a lot of value to GIS that is not yet being fully explored in transit operations and planning.

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The San Diego Association of Governments (SANDAG) is the regional planning agency and the metropolitan planning organization for the San Diego region. A major emphasis at SANDAG is on assisting the region's transit operators in their planning and marketing activities by providing technical assistance and data, including geographic analysis, data collection and management, survey research, and transportation modeling. Currently, SANDAG and the region's operators are working together to design a desktop geographic information system application that staff from each individual operator can access directly to enhance regional transit planning and marketing. The objective is to develop a tool that can be used directly by transit operator staff at a relatively low cost and with minimal training. Operators now have access to a variety of databases, including census data, passenger counts, and regional growth forecasts that can be integrated and displayed in map, table, or chart form. Planning and marketing efforts to enhance the current level of transit service and increase ridership in the region are benefiting from the coordination of this project between SANDAG and the transit operators.

GeoGraphics Laboratory at Bridgewater State College, Bridgewater, Mass. [Online]. Available: http://geolab.bridgew.edu/home/.

In 1994, the FTA moved to increase the potential power and scope of geographic information systems (GIS) in the transit industry through the Transit GIS Initiative, which was an integral part of the National Spatial Database Infrastructure Initiative. In doing so, the FTA made a commitment to the development of transit GIS databases, which provide essential information for the use of GIS software. By the Fall of 1996, 530 of the nation's fixed-route bus services had been built into GIS route systems by students and staff of Bridgewater State College (BSC). By early 1999, all fixed-route bus services had been completed. In an effort to promote the use of GIS as an analytical tool within the transit industry, FTA and BSC have shared these internal GIS data products for planning and research purposes through the website.

Hillman, R., "GIS-Based Innovations for Modelling Public Transport Accessibility," *Association for Geographic Information 97 Conference Proceedings: Geographic Information—Exploiting the Benefits*, Birmingham, England, 1997.

An analysis of a public transportation network's access points, interchanges, and intended routes was done to develop sustainability in transport planning. Demographics and travel patterns were the primary variables. A geographic information system was used to calculate accessibility indices, and the system added value to the entire transportation scheme studied.

Huang, R. and P. Zhong-Ren, "Object-Oriented Geographic Information System Data Model for Transit Trip-Planning Systems," *Transportation Research Record 1804*, Transportation Research Board, National Research Council, Washington, D.C., 2002, pp. 205–211.

The transit network has its unique characteristics, for example, multiple transit lines share the same street and stops, the same bus line runs on different streets during different times of the day, and some express lines only run at certain times of the day. These characteristics make it more difficult to design a network model than the street network. The conventional Entity–Relation model could make the network topology and data structure very complex and redundant. This paper presents a network structure for a transit network using Object-Oriented (OO) methods in which bus stops, timepoints, and vehicle routes, as well as the network are modeled as objects. Each object has spatial, temporal, and attributive properties, and can be created, transformed, and deleted. Therefore, the transit network can change based on the time. Routes, runs (services), timepoints, and stops that are not in service at the time of a trip are not presented in the dynamic topology. This OO model can reduce network and database redundancy and improve performance. The OO-based transit network model allows a more efficient network analysis and the shortest path search. Conceptual design of the model is conducted in the Unified Modeling Language (UML). The model was to be implemented in the on-line transit information services for Waukesha County, Wisconsin.

Jia, W. and B. Ford, "Transit GIS Applications in Fairfax County, Virginia," *Journal of Public Transportation*, Vol. 2, No. 4, 1999, pp. 41–59.

The Fairfax County Department of Transportation (DOT) manages a fixed-route bus system (the Fairfax Connector) with 58 routes. To better support the planning, operation, and marketing of this bus system, the Fairfax County DOT and the Fairfax County Department of Information Technology formed a team to develop a pilot project of geographic information systems transit applications. These applications would serve as a demonstration to facilitate automation, analysis, accessing, and plotting of transit data. To be successful, the applications had to be cost-effective and match users' technical needs with their abilities. Paramount to the success of this project was having a transit database capable of supporting all the applications identified by the development team. More than 15 applications were identified for 3 areas of transit management: planning, operation, and marketing. Planning applications focused on transit service improvement and route restructuring. They included routing adjustment, route demographic and land-use analysis, and reporting of statistics required by the National Transit Database. Operation applications were designed for daily service monitoring and consisted of route running times, loading at bus stops, and emergency service. Marketing applications emphasized functions for public outreach, which included creating specialized route and stop maps and publishing route information on the Internet.

Koncz, N. and J. Greenfeld, "GIS-Based Transit Information Bolsters Travel Options," *GIS World*, Vol. 8, No. 7, 1995, pp. 62–64.

This article reports on the variety of public transportation modes that exist in urban areas and how each of these modes has different methods for providing information to its potential users. Additionally, each mode uses several independent carriers to execute the service. The results were more accurate and timely when there were efforts using a geographic information system to coordinate the supply of information. It was also proved that unless such information is supplied in a convenient and friendly form, potential users are less likely to use public transportation.

Miller, H.J. and S. Shaw, *Geographic Information Systems for Transportation: Principles and Applications*, Oxford University Press, New York, N.Y., 2001.

Geographic information system (GIS) data and tools are revolutionizing transportation research and decision making, allowing transportation analysts and professionals to understand and solve previously unsolvable, complex transportation problems. The book presents a comprehensive discussion of fundamental geographic science and the applications of these principles using GIS and other software tools. By providing thorough and accessible discussions of transportation analysis, including transit, within a GIS environment, this volume fills a critical niche in GIS for Transportation (GIS-T) and GIS literature.

Miller, S.R. and T. Collins, "Using GIS to Analyze Potential Paratransit Fare and Zone Changes," *Proceedings of the Twenty-First Annual ESRI User Conference*, San Diego, Calif., 2001.

Two independently run public paratransit systems were used in Phoenix. As independent entities, the two systems differed in fares, hours, and zones. Consolidation was proposed, and a GIS was employed to find the best practices used in both transit systems so that the consolidation would be an easy transition for the previously divided group of users. The study also proved the effectiveness of GIS applications in solving specialized transportation needs.

National Transit Geographic Information System, Federal Transit Administration, Washington, D.C. [Online]. Available: http://www.fta.dot.gov/library/technology/GIS/nt_gis. htm.

The FTA National Transit Geographic Information System is a representative inventory of the public transit assets of the country. Creation of this national system is an ongoing and collaborative effort on the part of many within the transportation industry. Use of these transit data will facilitate the exchange of information within the U.S.DOT and throughout the transit industry. Locally, transit managers will have access to information that will allow them to better use resources and make more informed policy, operations, and planning decisions. At the national level, this information will represent the nation's public transportation infrastructure throughout the country. It will also facilitate improved analysis of policy and planning decisions.

National Transit GIS Data Standards, Guidelines, and Recommended Practices, Federal Transit Administration, Washington, D.C. [Online]. Available: http://www.fta.dot.gov/library/technology/GIS/ntgistds/NTGISTDS.HTM.

The *Standards, Guidelines, and Recommended Practices* establishes a framework for maintaining the National Transit Geographic Information System (NTG) database, and ensuring data integrity, interoperability, and consistency. The methods and quality control used in creating, storing, exchanging, and documenting the data in the NTG is known by recommending feature-type definitions, formats, file formats, update procedures, and other standards. The document outlines Feature Type Definitions and Descriptions, Addressing and Street Naming Conventions, Feature Type Automation and Conversion Guidelines, Transfer Formats, and Update and Maintenance Procedures.

Pulugurtha, S.S., S.S. Nambisan, and N. Srinivasan, "Evaluating Transit Market Potential and Selecting Locations of Transit Service Facilities Using GIS," *Journal of Public Transportation*, Vol. 2, No. 4, 1999, pp. 75–94.

Accessibility to transit service facility (TSF) locations plays a significant role in the success of public transportation systems. The ease with which the end-user can reach a TSF (e.g., bus stops, rail stations, or multimodal centers) plays prominently in the decision-making process of the individual. This article presents a working definition for transit market potential based on accessibility in terms of walking distance and walking time. Furthermore, a measure is constructed to evaluate transit market potential for TSF locations for a transit system. The measure of transit potential is represented by an index value based on demographic criteria such as employment, household size, vehicle ownership, etc. This index can be used to identify locations of TSFs that increase a route's potential for ridership. A methodology is proposed to estimate the Index of Transit Potential for TSFs. This methodology involves (1) identifying the accessible network of streets around each TSF that is within an acceptable access threshold for a transit rider, and (2) estimating the transit market potential based on key demographic characteristics. The analytical and visualization capabilities of a geographic information systems program are used to help attain the objective. A case study is used to demonstrate the application of the methodology. In the case study, a portion of a route of the Las Vegas Citizens Area Transit system is analyzed and the Index of Transit Potential is estimated. The index values are then used to locate TSFs along the route. This is compared with the existing stop locations for the route.

Rasmussen, T., "Public Transportation—Planning and Analysis Using GIS," *Proceedings of the Nineteenth Annual ESRI User Conference*, San Diego, Calif., July 26–30, 1999.

Several cases of transportation companies are analyzed based on their information systems. Most are using geographic information system tools such as ArcView to aid in the management of information about travel patterns and the planning that result in these patterns. A transportation company in Sweden, which does not currently use GIS tools (1999), is used as a case study to prove the effectiveness of implementing such a system.

Sanchez, T.W., "A Transit Access Analysis of TANF Recipients in Portland, Oregon," *Journal of Public Transportation*, Vol. 2, No. 4, 1999, pp. 61–73.

Little evidence exists regarding the relationship between transit service availability and the ability of welfare recipients to find stable employment. Although policymakers continue to assert that increased public transit mobility can positively affect employment status, there is little empirical evidence to support this theory. It is generally assumed that public transit can effectively link unemployed, carless persons with appropriate job locations. From these assumptions stems the common belief that if adequate transit were available, the likelihood of being employed would increase. Hence, the call for more transit services to assist in moving welfare recipients to gainful employment. Current available evidence is anecdotal, although general patterns of transit access and labor participation remain relatively unexplored. This analysis examines whether transit access service is less available to Temporary Assistance for Needy Families (TANF) recipients in the city of Portland, Oregon. It uses disaggregate TANF recipient location data from the state of Oregon Department of Adult and Family Services, transit route and stop data from TriMet, block-group census data, and disaggregate employment location data within geographic information systems (GIS). GIS capabilities are essential in performing network accessibility analyses and for analyzing spatial patterns of TANF recipient and employment locations. The results of this analysis provide an assessment of the availability and quality of transit service for TANF recipients.

Shiffer, M.J., "Spatial Multimedia for Planning Support," in *Planning Support Systems*, Paper 13, R.K. Brail and R.E. Klosterman (eds.), ESRI Press, Redlands, Calif., 2001.

Collaborative community planning with extensive involvement has emerged as a central component of public policy. There are a variety of ways in which the public can share knowledge about their communities, and there are advantages and limitations to each of these approaches. Spatial multimedia refers to the integration of video, sound, and text within a distributed environment. Within this general approach, the paper discusses spatial annotation, visual navigation aids, and devices for scenario construction. Implementing spatial multimedia can be done at different levels—face-to-face and in both centralized and distributed contexts.

Sirota, S. and V. Henry, "Using GIS to Identify Locations with the Greatest Potential Increased Light Rail Ridership," *Proceedings of the Eighth Annual Symposium on Geographic Information Systems for Transportation* (*GIS-T*), Sparks, Nev., 1995, pp. 371–382.

A geographic information system (GIS) was used in a marketing scheme for a light-rail company in Baltimore, thus furthering the versatility of GIS tools. Specific target markets were identified, combined with the spatial analysis of the GIS. In using the GIS, the light-rail management was able to identify specific transportation analysis zones; these zones provided the management with markets of new ridership potential. The colorful maps supplied top management with an easy-to-read interpretation of the data.

Spear, B.D. and R.W. Weil, "Access to Intercity Public Transportation Services from Small Communities: Geospatial Analysis," *Transportation Research Record 1666*, Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 65–73.

This study analyzes the political implications of public transportation needs and the role that the federal government should and should not play in those needs. Geographic information system (GIS) technology provided spatial analyses. The results isolated areas that were underserved by public transportation and the correlative economic conditions that accompany them. The GIS then created buffers to identify areas that were beyond reasonable access to intercity transit systems. The study analyzed by the authors was done by the U.S.DOT and would not have been feasible without the use of GIS.

Tornberg, J. and J. Bjurstrom, "Visualization and Animation in Design of a New Transportation System in Existing Urban Environment Using GIS and Virtual Reality," *Proceedings of the Twentieth Annual ESRI User Conference*, San Diego, Calif., June 25–28, 2000.

In an attempt to alleviate the increasing demand for public transportation in Gothenburg, a virtual city was built at Chalmers University to visualize what effects an aerial cableway would have on these demands. The 3-D model was developed using Arc/Info, ArcView, and TerraVista. The model made it possible to take a virtual tour of the cableway. The authors concur that GIS and virtual reality technology will be indispensable for transportation planners in the future.

Zhang, M., "Accessibility Enhancement—Understanding the Benefit of Rail Transit Systems," *URISA 97 Annual Conference Proceedings*, Toronto, ON, Canada, 1997.

This study examines the benefit of rail systems in transit-dependent populations. The author uses data from case studies done in Boston, Miami, and Atlanta. Accessibility of users is the key factor in the analysis. Arc/Info and other database management systems assist in visualizing the research results.

GLOSSARY OF TERMS AND ACRONYMS

ACID	Accident and Incident Tracking System
ADA	Americans with Disabilities Act
APC	automated passenger counting
APTS	Advanced Public Transportation Systems
AVL	automatic vehicle location
BTS	Bureau of Transportation Statistics
BUDS	BDS Display System
CAD	computer-aided dispatch
CTA	Chicago Transit Authority
CUTR	Center for Urban Transportation Research
DBMS	database management system
DGN	Design File
DIME	Dual Independent Mapping Encoding
DOT	Department of Transportation
FTE	full-time equivalent
GDF	Geographic Data File
GIS	Geographic Information System
GIS-T	Geospatial Information Systems for Transportation
GML	Geographic Markup Language
GOS	Geospatial One-Stop
GPS	global positioning system
IMS	Internet Map Server
ISO	International Standards Organization
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
IT	information technology
ITE	Institute of Transportation Engineers
ITS	intelligent transportation systems
LIDAR	Light Detection and Ranging
LRS	linear referencing system
MDT	Miami–Dade Transit
MFS	Map Feature Standard
MPO	metropolitan planning organization
NCGIA	National Center for Geographic Information and Analysis
NEMA	National Electronic Manufacturers Association
NSDI	National Spatial Data Infrastructure
NTCIP	National Transportation Communication for ITS Profile
OCTA	Orange County Transportation Authority
OGC	Open GIS Consortium
ROMANSE	Road Management System for Europe
RTD	Regional Transit Database
RTIS	Regional Transit Information System
SAE	Society for Automotive Engineers
SAM	Stops and Amenities Maintenance
SDE	spatial data engine
SDO	spatial data object
SOAP	Simple Object Access Protocol
TCIP	Transit Communication Interface Profile
TEA-21	Transportation Equity Act for the 21st Century
TED	Transit Enterprise Database
TIGER	Topologically Integrated and Geographic Encoded Reference System
TNET	Transportation Network
TOP	Transit Operations Toolbox
TransFM	Transit Feature Management
TRUST	TRANSMODEL Users Support Team
UNETRANS	Unified Transportation and Network System
WFS	Web Feature Standard
XML	Extensible Markup Language

APPENDIX A

Case Study Questionnaire and Interview Guide

TRANSIT COOPERATIVE RESEARCH PROGRAM

Synthesis Topic SH-03

APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN TRANSIT PLANNING AND OPERATIONS

Case Study Questionnaire/Interview Guide

Purpose of this survey. Over the years, GIS technology has been implemented for a variety of purposes within the transit industry. With this have come many new uses, benefits, and challenges. The purpose of this survey is to document current practices, effective applications, and challenges among leading edge transit agencies. The survey will collect basic information to be supplemented by a detailed case study of your agency.

1. Please provide your contact information.

First name: ______________________ MI: ____________________

Last name: ____

Title: ____

Organization: ____

Street: ____

City: ____

State: _________________________ Zip code: _________________

Phone: _________________________ Fax: ____________________

E-mail: _________________________

2. General information on transit agency.

Service Area Size

No. of counties ______________________________

No. of cities ______________________________

Service area square-miles ______________________________

Service area population ______________________________

Agency Size

Size of fixed-route bus fleet ______________________________

Annual revenue vehicle-miles ______________________________

No. of routes ______________________________

No. of stops ______________________________

Annual passenger trips ______________________________

Size of paratransit bus fleet ______________________________

Size of rail/light-rail fleet ______________________________

3. What type of GIS services do you provide?

Available GIS Services	In-House %	External Contracts %
Application development		
Data collection		
Map production including cartography		
Training		
Technical support/systems integration		

4. In which areas of your organization is GIS used? (Choose all that apply.)

For each application area list the software currently used, whether GIS based or not, and indicate if a digital centerline file is required and whether this is maintained in the GIS.

		Transit Applications Software (list all products in use whether GIS based or not)			Network Data Management			
GIS Application Areas (mark “X” all those that apply)	GIS	Software	Version	Status	Centerline Basemap Required	Centerline Source	Update Cycle	Maintained in GIS?
Service planning								
Market analysis								
Map products design and publishing								
Fixed-route scheduling								
Interactive itinerary travel planning								
Kiosk based								
Internet based								
Ridematching (for car and van pools)								
Transit pass use								
Turnstile/platform data collection								
Onboard vehicle data collection with GPS								
Automatic passenger counting								
Smart card								
Automatic vehicle location								
Real-time schedule display								
Paratransit scheduling and dispatching								
Real estate asset management								
Police operations								
Security								
Criminal investigation								
Counterterrorism								
Accident/incident reconstruction								
ADA compliance								
Title VI of Civil Rights Act								
Welfare to work								
Human services transportation coordination								
New starts supporting land use criteria								

5. Which GIS product(s) do you use? (Choose all that apply.)

GIS Software Used	No. of Licenses/Users in Agency (do not include run-time)
ArcView 3.x	
ArcView 8.x	
Arc/Info	
Map Objects	
GeoMedia	
Intergraph MGE	
MapInfo	
Autodesk Map	
Oracle Spatial	
TransCAD	

6. Do you integrate remotely sensed imagery into your GIS?
If Yes, what is the source and type of your imagery?

Aerial Photography (list all applications and sources)	Source	How Often Is it Purchased?	Level of Accuracy/ Resolution	Cost	No. of Images

7. Are you using web–GIS services? (If yes, please provide details.)

Internet	Map Server Software	Used to Access GIS Data	Used to Access GIS Applications	Provides Real-Time Bus Location Information
Map server for internal customers				
Map server for external customers				

8. What types of data are stored electronically? (Choose all that apply.)

GIS Data (complete all that apply)	Maintained by GIS Department	Maintained by Business User (e.g., scheduling)	Maintained by External Agency (e.g., MPO)	Data Format*	Database Software Used	Level of Accuracy (%)	Complete -ness (%)	Update Cycle (monthly, quarterly, yearly)	GPS Utilized to Collect/ Maintain Data
Bus routes									
Bus stops									
Stop amenities									
Time points									
Transit centers									
Park and rides									
Light rail lignment and stops									
Landmarks									

GIS Data (complete all that apply)	Maintained by GIS Department	Maintained by Business User (e.g., scheduling)	Maintained by External Agency (e.g., MPO)	Data Format*	Database Software Used	Level of Accuracy (%)	Complete -ness (%)	Update Cycle (monthly, quarterly, yearly)	GPS Utilized to Collect/ Maintain Data
Transit boundary									
ADA boundary									
Transit facility locations									
Traffic signals									
TAZ traffic analysis zone boun-daries									
Census data									
Accidents and incidents									
Customer com-plaints									
Political boun-daries									

*e.g., Shapefile, Arc/Info coverage, CAD, and *x/y* coordinates.

9. General information on IT infrastructure.

IT Infrastructure	
Agency RDBMS	
Server Operating System	
Client Operating System	

10. Information on staffing and budget.

Staffing and Budget	Nos.
Administrative staff	
IT staff	
Annual IT budget	$ —
GIS Staff (does not include users):*	
GIS coordinator or manager	
GIS analyst	
GIS technician	
GIS programmer/developer	
Annual GIS budget	$ —

*Full-time equivalent.

11. Which department manages the GIS? ___________________________________

Please return the completed questionnaire to:

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Senior Associate
Cambridge Systematics, Inc.
4445 Willard Avenue, Suite 300
Chevy Chase, Maryland 20815
Tel. (301) 347-0128
Fax: (301) 347-0100
E-mail: jsutton@camsys.com

APPENDIX B

Case Study Participants

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APPENDIX C

Transit Geographic Information Systems Benefits: Respondents Comments to 1993 Survey

The following is a sample of the comments made by transit agencies to the perceived benefits of GIS to their agency in the FTA-sponsored survey conducted by Bridgewater College in Massachusetts.

- "GIS has benefited our organization by allowing us to capture, analyze, and distribute a greater volume and complexity of data to our entities." ACOG, Oklahoma City, OK
- "We all benefit from GIS, in that it is a tool that helps people grasp a concept by viewing it spatially." RADCO/FAMCO, Fredericksburg, VA
- "Integrated data and geography. Allows enhancement of data analysis and spatial relationships. Automates operations." Capitol District Transit Authority, Albany, NY
- "Allows us to match bus routes with city services and census data." Indianapolis Public Transportation Corporation, Indianapolis, IN
- "We can measure phenomena, analyze relationships, and otherwise make better decisions. We have also found that the GIS system outputs (maps and reports) are more effective communications tools." Metropolitan Council, St. Paul, MN
- "Increases productivity, improves interagency sharing and coordination of geospatial information." Abilene MPO, Abilene, TX
- "Produce better maps/displays for reporting to governing board. Better ability to visualize ridership data and bus stop information for greater comprehension of ridership patterns. Ease of analysis of ridership with respect to route segments." Milwaukee County Transit System, Milwaukee, WI
- "Integrated separate databases into one centralized GIS." Regional Transit District, Denver, CO
- "Excellent tool for analyzing policy issues (population served, market share, potential ridership, etc.). For customer service, we have included a map-based schedule on the web to provide schedules at each bus stop. Also, we use GIS for our bus stop database to identify locations and signage/facilities at each stop." Unitrans, Davis, CA
- "It has aided us in developing paratransit maps for ADA compliance to illustrate that % mile outside of our fixed-route system. This assures MTA is (1) ADA compliant, (2) It has matched ridesharing for vanpools/carpools, and (3) It has aided in developing maps for transit service planning." Des Moines MTA, Des Moines, IA
- "Visual graphics help communicate answers to problems. Thematic mapping is excellent tool. GIS offers numerous tools: database analysis, charts, maps, etc." Central Ohio Transit Authority, Columbus, OH
- "Helps keep our vehicles on time and on route. It also helps resolve issues with passenger stating vehicle never arrived." Greater Attleboro—Taunton RTA, Taunton, MA
- "Primarily as an internal engine to our CAD/AVL system for regular route dispatching. Also, for demographic analysis using passenger data and as a map edit maintenance tool." Capital District Transit Authority, Albany, NY
- "Allowed staff to analyze census/CTPP (Census Transportation Planning Package) data in graphic form." Lawton MPO, Lawton, OK
- "It has helped our dispatching operations tremendously. There is still so much more that it could do for us if we had the manpower to help make our software work for us." Brazos Transit District, Brazos, TX
- "Quality, accuracy, and productivity of work have greatly improved." VIA Metropolitan Transit, San Antonio, TX
- "GIS enables our agency to provide automated trip itinerary planning. It enhances our strategic and service planning capabilities and it contributes to the improved efficiency and safety of our transit operations." Community Transit, Everett, WA
- "It has made us more productive in working on bus stops and route planning. It has made AVL technology available and useful." City of Visalia, Visalia, CA
- "GIS programs and maps have been widely utilized to assist service planning, transportation demand modeling, policy analysis, and presentations of major transportation improvement projects in Los Angeles County." LA County MTA, Los Angeles, CA
- "We are able to track their movement, identify customer stops, and assign new passengers to best suited routes." Ottumwa Transit Authority, Ottumwa, IA
- "Ability to do computer-assisted paratransit scheduling, ADA complementary paratransit trip eligibility, flex-route planning, demographic analysis of service alternatives, thematic mapping of service usage for community presentations; soon to add AVL and MDTs." York County Transportation Authority, York County, PA
- "GPS and GIS have given us automatic passenger counting capabilities for bus and light rail plus a dis-

tributed analytical tool for route effective/efficiency analysis." Bi-State Development Agency, St. Louis, MO

- "Improved communication of information to public, co-workers, and decision makers. Facilitates the processing, analysis, and storage of all data with a spatial component." Baltimore Metropolitan Council, Baltimore, MD
- "Publishing maps, integrating databases, travel-demand forecasting, analyzing ridership trends, facilities management. Basically, it gives us a tool to get departments to share data that we did not do previously." Washington Metropolitan Area Transit Authority, Washington, DC
- "GIS has allowed the LVPC to develop applications that assist us in our spatial analysis. GIS is used in the development of the Lehigh Valley regional travel model, Welfare-to-Work analysis, socioeconomic projections, determinations of ADA service areas, etc." Lehigh Valley Planning Commission (LVPC), Allentown, PA

APPENDIX D

Application Areas for Non-Geographic Information System Software

Application	TriMet	King County	NJ Transit	Miami–Dade Transit	CTA
Service Planning		x	In-house	x	x
Fixed-Route Scheduling	HASTUS	HASTUS	CASS (in-house)	Trapeze	HASTUS
Interactive Itinerary Travel		ATIS/Trapeze			
Kiosk-based				Trapeze	
Internet-based	ATIS/Trapeze	ATIS/Trapeze	ATIS/Trapeze	Trapeze	
Ridematching	Regional application				
Onboard Vehicle Data Collection with GPS	Orbital		Mixed custom, GIS, Pathfinder Office	MA/COM	Clever Devices
Automatic passenger counting	Orbital	In-house	Orbital		Clever Devices
Smart card		ERG			Orbital
Display of Automatic Vehicle Location	Orbital and in-house application	In-house		MA/COM	Orbital
Real-Time Bus Display	In-house	Custom		MA/COM	
Paratransit Scheduling and Dispatching	Trapeze	Trapeze	Trapeze		
Real Estate Asset Management		In-house			
Police Operations					
Security		In-house			
Criminal investigation	In-house				

Abbreviations used without definition in TRB Publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation