Review of Data Integration Practices and their Applications to Transportation Asset Management

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16. Abstract

Data integration is a fundamental requirement for Transportation Asset Management, a strategic approach to maximizing the benefits from resources used to maintain, operate and expand the transportation infrastructure. The goal of data integration is to consolidate or link the data that exist in separate files or database systems so they can be used to make decisions within and across asset types. States and local agencies know that without an integrated set of data they can never make strategic and comprehensive transportation investment decisions.

The Federal Highway Administration (FHWA) Office of Asset Management has made data integration a priority for its research, development and deployment programs. The Office has been delivering an array of products and materials to inform transportation agencies about the strategies and benefits of data integration, and providing technical support to help those agencies with their data integration initiatives particularly in overcoming the impediments.

One of the products identified as highly valuable to Asset Management practitioners is a state-of-the-practice synthesis of data integration initiatives across the country. This report contains a review and synthesis of data integration practices among transportation agencies at the State and local levels. While it does not include all data integration initiatives across the country, it provides a broad picture of the state-of-the practice and a compelling basis for detailed case studies.

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prepared by

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Executive Summary

Data integration is a fundamental requirement for Transportation Asset Management, a strategic approach to maximizing the benefits from resources used to maintain, operate and expand the transportation infrastructure. The goal of data integration is to consolidate or link the data that exist in separate files or database systems so they can be used to make decisions within and across asset types. States and local agencies know that without an integrated set of data they can never make strategic and comprehensive transportation investment decisions.

The Federal Highway Administration (FHWA) Office of Asset Management has made data integration a priority for its research, development and deployment programs. The Office has been delivering an array of products and materials to inform transportation agencies about the strategies and benefits of data integration, and providing technical support to help those agencies with their data integration initiatives particularly in overcoming the impediments.

One of the products identified as highly valuable to Asset Management practitioners is a state-of-the-practice synthesis of data integration initiatives across the country. Agencies interested in integrating data for Transportation Asset Management will benefit from knowing what others are doing and the software, tools and methods they have adopted to support data integration. Additionally, they can draw important lessons from those experiences to guide their own implementation efforts.

This report contains a review and synthesis of data integration practices among transportation agencies at the State and local levels. While it does not include all data integration initiatives across the country, it provides a broad picture of the state-of-the practice and a compelling basis for detailed case studies. The report consists of five parts as follows:

1.0 Literature Review – Includes a list with brief description of documents, articles, publications, and other reference materials on data integration. The literature is obtained mostly from published documents and web site materials, and is summarized in terms of which aspects of data integration are being addressed.

2.0 Detailed Review of Data Integration Practices – Summarizes the data integration practices of selected transportation agencies based on the literature review. The detailed reviews describe the data being integrated and for what purpose, the software and tools used, the problems encountered and lessons learned, and the agency's future plans.

3.0 Professional Groups and Organizations Involved in Data Integration – Identifies various public and private industry groups and organizations that are addressing data integration issues. The mission, activities and products of these groups are documented.

4.0 Innovative Data Integration Practices and Tools – Describes innovative software, tools and methods applied by transportation agencies for data integration as documented in the detailed reviews. The advantages and disadvantages of the practices and their implications for Asset Management data integration are also described.

5.0 Conclusions and Recommendations – Provides a summary of the research study and a set of recommendations for detailed case studies.

Task 1.0 – Literature Review

A significant body of literature can be found on data integration. For transportation applications, data integration initiatives have been documented in a variety of materials including those published by the Federal Highway Administration (FHWA), the Transportation Research Board (TRB), the National Cooperative Highway Research Program (NCHRP), and other organizations. The World Wide Web also provides a convenient medium by which to access and share information regarding data integration activities of transportation agencies.

This research study began with a review of literature describing data integration practices in transportation agencies. The information is obtained from published reports and journals, conference and peer exchange presentations, electronic web sites, and other documentations. To focus on more recent literature, the review was limited to 1990s and beyond. While a great deal of the material reviewed pertains to highway agencies, a few involved transit agencies.

The literature review is divided into three parts. The first part includes general literature on data integration techniques and issues for transportation agencies, including references that synthesize experiences from a number of different agencies. The second and third parts describe data integration literature pertaining to State and local transportation agencies, respectively. For each part, brief summaries of relevant documents are provided from most recent to earliest. Each source document is referenced by a number enclosed in parentheses.

A table at the end of the section summarizes the literature reviewed and identifies the specific aspects of data integration addressed.

■ General Data Integration

A GIS-T Approach to Integrating Asset Management and Maintenance Management (1)

This presentation addresses the lack of effective business processes for updating asset features, attributes, and condition changes in asset management systems as the result of ongoing maintenance, repair, and replacement activities. It discusses the integration of maintenance management planning, scheduling and performance data with asset management data in a GIS-T environment.

NATMEC Presentation on Integration of Data Sources (2)

In a presentation at the 2002 North American Travel Monitoring Exhibition and Conference (NATMEC 2002), the TRB Committee on Spatial Data and Information Science outlined drivers of data integration and presented a list of questions that can help determine if an agency is prepared for data integration. The questions are summarized as follows:

- Assigning clear roles (e.g., Do clear data management policy goals and objectives exist within the agency?);
- Providing transparent technology (e.g., Does the agency have a methodology for integrating data and a toolset that supports this methodology?);
- Defining globally, deploying incrementally (e.g., Are data integration objectives clearly linked to the agency's business plan and initiatives?);
- Balancing enterprise and local perspectives (e.g., Does the agency view data as an enterprise asset rather than as a programmatic resource?); and
- Collaborating across institutional boundaries (e.g., Have partnerships amongst data producers and consumers been established?).

Cost and Benefits of Using Intelligent Transportation Systems as an Alternative Data Source: Case Study (3)

This report describes a case study of the costs and benefits of using ITS-generated traffic data as a data source to address traffic monitoring requirements. The costs were measured in terms of the effort needed to archive and reformat the data, revamp the software, and address data quality and data integration issues. The benefits were measured in terms of the value added by the ITS-generated data. The study indicates that although the costs are high to use ITS-generated data for purposes other than the originally intended use, the ITS-generated data when integrated with other data can improve transportation decisions.

Asset Management Model and Systems Integration Approach (4)

This paper presents an asset management model for systems integration that demonstrates how asset management systems can be integrated at different stages of their development. The paper defines five phases of integration:

1. Business integration;
2. System Requirements integration;
3. Logical design integration;

4. Physical design and development integration; and
5. Implementation Integration.

Achievements of the DOT-NASA Joint Program on Remote Sensing and Spatial Information Technologies: Application to Multimodal Transportation (5)

Remote sensing is an emerging technology in transportation data collection and monitoring. Examples of how remote sensing methods can be used in transportation, including data integration, are illustrated in a report sponsored by NASA and the U.S. DOT. The report highlights recent progress in applying commercial remote sensing and geospatial technologies. Research into the application of remote sensing in transportation is being coordinated by the U.S. DOT's Research and Special Programs Administration through four consortia that focus on likely application areas including infrastructure management. The infrastructure management consortium includes examples of asset management applications such as the use of Light Detection and Ranging (LIDAR) to improve highway location planning and design (Iowa DOT), development of a tool to facilitate bridge management (Wisconsin DOT), and application of high-resolution commercial satellite imagery to analyze intermodal connectors along the Alameda corridor (Los Angeles).

NCHRP Project 20-5 – Collecting, Processing, and Integrating GPS Data into GIS (6)

The scope of NCHRP Project 20-5 "Synthesis of Information Related to Highway Problems" included development of a synthesis of highway practice for the collection, processing, and integration of GPS data into GIS. The findings of this study are documented in *NCHRP Report 301*. The focus of the synthesis is on the major issues associated with GPS and GIS data integration and how to address them for digital mapping applications related to transportation. The synthesis includes a literature review, a survey of 47 practitioners in state DOTs, MPOs, and other transportation agencies, and a review of map matching algorithms. The report also defines the following six-step methodology to improve the quality of maps and reduce the severity of problems associated with GPS-GIS integration:

1. Project definition and GIS base map selection;
2. GPS data collection;
3. Quality assurance check (data review and adjustments);
4. Matching GPS data on to a base map in a GIS;
5. Application and output; and
6. Data maintenance and base map improvement.

The Role of GIS in Enterprise Data Sharing Frameworks (7)

This presentation discusses the appropriate role for GIS in enterprise databases that provide a mechanism for enterprise data to be shared among different departments of an agency, and provides examples from the British Columbia Roadway Information Management System.

Using Location to Integrate Local and State Government Road Information (8)

The presentation describes a project initiated by the city of Rochester and Olmstead County, Minnesota to improve the transfer of road information between multiple government departments, including Minnesota DOT, via location referencing. This project is an example of interagency data integration.

Integrating and Using Highway Dynamic Data with Relatively Infrequently Published GIS Data (9)

This presentation describes methods to provide information on temporary or permanent changes to the existing highway system that result in changes to GIS attributes (e.g., closure of a lane for maintenance work) without the need to release a new GIS dataset. The presentation discusses ways of applying dynamic information to relatively static GIS datasets.

Spatial Solutions for Document and Information Management (10)

This presentation describes a general GIS-based Electronic Data Management System (GIS/EDMS) solution. Such a solution provides a method of integration based on spatial technology and traditional information management systems. Using GIS/EDMS, a user need only know the approximate location of a project on a map to locate all relevant information (e.g., inspection reports, maintenance data, encroachment permitting, and engineering data) using spatial features as a primary key. The presentation also includes examples of completed and current projects.

TRB Peer Exchange on Integrating Highway Information (11)

In March 2001, the TRB Committees on Transportation Data and Information Technologies sponsored a peer exchange on Integrating Highway Information. The objectives of this exchange were to provide a forum for state and local transportation agencies to exchange ideas, develop data integration principles, identify success factors, and discuss next steps. The findings of this exchange are documented in a report that presents five principles of successful data integration efforts and identifies success factors for each:

1. Assign clear roles and responsibilities;

2. Enable transparent access to information from multiple sources;

3. Develop a comprehensive plan and implement it incrementally;
4. Balance internal and external needs for information; and
5. Provide public access to information.

The report also provides detailed information on the status of data integration efforts at eight state departments of transportation (Florida, New York, Virginia, Maine, Minnesota, Kansas, Michigan, and Wisconsin), two Metropolitan Planning Organizations (Pima Association of Governments, Baltimore Metropolitan Council), and one city (Jacksonville, Florida).

FHWA Forum and Peer Exchange on Data Integration for Asset Management (12)

In December 2001, the FHWA Office of Asset Management and AASHTO sponsored a forum and peer exchange on Data Integration for Asset Management. The findings of this exchange have been documented by the FHWA and AASHTO. This report provides presentation highlights from seven state DOTs (Florida, Maine, Michigan, Mississippi, Ohio, Tennessee, and Virginia) on the status of individual data integration efforts. The report identifies the following common integration issues and challenges:

- Data content, format, and sources;
- Legacy database and decision support systems;
- Data interoperability and standards;
- People and organizational culture;
- Data integration architecture and strategy;
- Locational referencing;
- Integrated analysis and decision-making; and
- Database management technology.

NCHRP Project 20-24[11] Asset Management Guidance for Transportation Agencies (13)

Phase I of NCHRP Project 20-24[11] resulted in a series of three reports that provide a synthesis of asset management practices, present a transportation asset management framework, and recommend a prioritized program of research in asset management. Section 4 of the Task 2 report, *Asset Management Framework*, includes a detailed discussion of information technology supporting asset management, and stresses the importance of efforts to promote data integration. This section covers the different types of management systems and data which are used to support asset management, discusses challenges to improved capabilities (including data integration), and presents a set of sample information system requirements which have relevance for data integration. The section then identifies three key areas where better integration may be considered, including data collection, processing, and storage; queries of asset conditions, needs and planned projects; and establishing a consistent evaluation framework in analyzing projects and programs. Finally, a set of options are presented for data management and integration, including use of data warehouses, building interfaces to legacy systems, establishing centralized databases, and using a distributed database approach.

Appendix A of the report provides an incremental approach for improving information systems for asset management. This Appendix suggests a flexible "tinker toy" model for asset management systems – in which a variety of specialized data sources and analytic tools are connected by a common framework. This framework consists of data interfaces (including common performance measures, geographic and temporal referencing systems, and data models) and process interfaces (including workflow coordination and negotiation of data standards). The Appendix also discusses technology infrastructure for achieving integration including data interchange standards, geographic information systems, networking and shared hardware resources, and shared software components.

FHWA Data Integration Primer (14)

The FHWA Office of Asset Management developed a *Data Integration Primer* to provide guidance to state and local transportation agencies that are developing or implementing data integration initiatives. The document discusses the benefits of data integration in the context of the asset management business process and presents a framework for data integration. This framework includes the following process steps:

- Requirements analysis;
- Data and process flow modeling;
- Alternatives definition, evaluation, and selection;
- Database design and specifications; and
- Development, testing, and implementation.

The primer also introduces several data integration alternatives and challenges. Brief examples of current DOT practices are provided throughout the document to illustrate key points. A comprehensive glossary of data integration terms also is provided in a companion document.

TRB Peer Exchange – Enhancing the Value of Data Programs (15)

In July 2001, the TRB Statewide Transportation Data Committee sponsored a peer exchange on "Enhancing the Value of Data Programs." The objectives of this exchange were to discuss the importance of data programs in supporting DOT decision-makers, identify common data gaps, and present best practices for developing a data strategy and addressing emerging challenges. A report was prepared by TRB presenting the findings of this exchange. It discusses the value of data, organizational issues, and the development of data programs. In addition, the document provides details on the data collection and integration efforts of eight state DOTs (Minnesota, Texas, Kentucky, Montana, Michigan, Florida, California, and New York).

Application Sharing: Best Practices and Lessons Learned (16)

The National Electronic Commerce Coordinating Council (NECCC) is a consortium of national and state government associations "dedicated to the advancement of electronic government within the states." In recognition of the opportunity for cost savings through the sharing of applications and information across government agencies, the Application Sharing Sub-Group of the 2001 e-Government Best Practices Workgroup prepared a white paper documenting the various aspects of application sharing. The paper presents a definition of application sharing, reviews the architecture and methodology behind application sharing, describes public and private perspectives, details best practices and lessons learned, and examines future trends in application sharing. These trends include: the sharing of whole applications by agencies, component-based development of applications, and reuse of code, state governments providing application services to local agencies, wireless networking, and peer-to-peer application service providers (ASP). The report also presents several case studies of application sharing among state transportation departments, and among other public agencies.

NCHRP Project 20-27[3] – Guidelines for the Implementation of Multimodal Transportation Location Referencing Systems (17) and GIS-T/ISTEA Management Systems Server-Net Prototype Pooled Fund Study Phase B Summary (18)

NCHRP Project 20-27[3] established functional requirements for a multimodal and multidimensional location referencing systems (MDLRS) that can be adopted by transportation agencies, geo-data standards groups, and Geographic Information System in Transportation (GIS-T) vendors. The results of this study are documented in *NCHRP Report 460.* This report also presents a MDLRS data model that meets these requirements and provides guidelines for its implementation by transportation agencies. The recommended MDLRS builds off of the LRS model previously developed through NCHRP 20-27[2]. This LRS has been implemented by several DOTs and has been incorporated into the GIS-T Pooled Fund Study Phase B (18) architecture. While the LRS model focuses on linearly referenced data (e.g., inventory and condition data), the MDLRS enables integration of linear data with data of up to four dimensions. An example of higher dimensional data is real time traffic data collected by an intelligent transportation system (ITS).

Data Warehouse Considerations in GIS-T (19)

This presentation examines the trend toward the establishment of formal data warehouse strategies and supporting frameworks within transportation agencies in support of corporate data access. It highlights operational and implementation issues through case study examples.

NSDI Framework Transportation Identification Standard (20) and a Data Foundation for the National Spatial Data Infrastructure (21)

The Federal Geographic Data Committee (FGDC) was established to promote the development, sharing, and use of geographic data. The FGDC created the Ground Transportation Subcommittee in order to focus on transportation data. This subcommittee recently published the National Spatial Data Infrastructure (NSDI) standards. This document outlines standards for transferring geospatial data related to transportation networks from Federal, state, and local agencies to a transportation layer of the NSDI framework database. It establishes a basis for information transfer across different networks, referencing systems, and cartographic representations.

In early 1993, the National Research Council's (NRC) Mapping Science Committee developed the concept of a National Spatial Data Infrastructure (NSDI) (21). The purpose of this report was to identify a foundation that provides a common reference system for the generation and exchange of spatial data. The report identifies three categories of spatial data that form the foundation for the NSDI, identifies minimum specifications required to integrate other spatial data with the foundation, and recommends specific activities that should be pursued to achieve an integrated and accessible NSDI.

Implementation of an Executive Information Management System (22)

This presentation describes the development of an Executive Information Management System (EIS), which provides access to enterprise-wide data sets at the Pennsylvania Turnpike Commission (PTC) within a single geographically based system, using a common graphic user interface and database viewer forms. The major components of the EIS include the following:

- Digital spatial data;
- Customized ARC/INFO and ArcView GIS software;
- New and existing attribute data;
- Database and spreadsheet applications; and
- A Visual Basic interface and a suite of custom applications.

Asset Management Peer Exchange: Using Past Experiences to Shape Future Practice (23)

In December of 1999, the American Association of State Highway and Transportation Officials and the Federal Highway Administration co-sponsored an executive workshop entitled "Asset Management Peer Exchange: Using Past Experiences to Shape Future

Practice." The goal of the workshop was to get state highway and transportation representatives together to share their asset management experiences including data integration. This article presents summaries of experiences in five states: New York, Minnesota, Virginia, Montana, and Michigan.

Spatial Data Handling for ITS: Perspective, Issues and Approaches (24)

This paper examines spatial data handling in Intelligent Transportation Systems (ITS), focusing on data management and processing; dynamic data integration; and data exchange and communications. Within these areas, the following topics are discussed: geographic information systems (GIS), electronic data interchange, database management systems (DBMS), location referencing, data dictionaries, data coding, and data models.

GIS-T as an Integral Component of ITS (25)

This presentation looks at the potential for using GIS to integrate the many separate ITS technologies into a single system that can be used in the management and operation of transportation infrastructure.

Object-Oriented Network Data Structures (26)

This presentation investigates the trend towards object-oriented data models among GIS and database vendors as a means of providing enhanced representation of transportation networks. It examines network data problems experienced by state DOTs, MPOs, and other transportation agencies, and provides examples from linear referencing, transportation modeling, and network integration.

Transportation Design Meets Transportation GIS: Sharing a Common Database (27)

This presentation describes a prototype system that integrates GIS and CAD data, including: road centerlines, land use/land cover polygons, cadastral data, satellite imagery, orthophotography, 2-D/3-D CAD drawings, and high-resolution photogrammetric, and LIDAR terrain data.

TRB Millennium Paper: Geographic Information Systems for Transportation – A Look Forward (28)

This paper explores future applications of GIS for Transportation (GIS-T). It discusses the following emerging issues identified by the TRB Committee on Spatial Data and Information Science:

- Geographic data interoperability;
- Legacy investments and procurement processes that hinder the implementation of new GIS-T technologies;
- Untrained consumers and lack of user-friendly interfaces;
- Need for large investments in data warehouses and integration of decision support systems with operational systems;
- Managing information glut;
- Lack of universal standards for metadata and public interfaces;
- Development of improved algorithms to integrate geographic and linear data; and
- Development and implementation of "open" data architectures and software.

TRB Millennium Paper: Information Technology in Transportation – Key Issues and a Look Forward (29)

This paper cites data sharing and interoperability as two of the growing concerns related to the application of advanced information technology in transportation. It identifies the following avenues to be pursued by the TRB Committee on Information Systems and Technology in the new millennium:

- Data storage and data delivery in a generic or non-data-specific way.
- Establishing formats and standards for dissemination of standardized transportation data sets.
- Further exploration of the data interoperability concept as a more realistic replacement for the concept of full data integration. Such exploration should include the role of standards, the differences between component and system-level interoperability, and documentation of early examples.

Development of Prototype Highway Asset Management System (30)

This paper describes a prototype methodology for integrating highway infrastructure management activities. This methodology consists of analytical procedures; data integration and presentation methods; a geographic information system GIS-based software system that ties everything together. There are four major areas of integration considered in the methodology:

1. Integrated computerized system;
2. Network-level integration;
3. Project-level integration; and
4. Multiple performance measures.

Spatial Data Integration and Interoperability for ITS (31)

This paper provides a discussion of the importance of spatial data integration and interoperability in support of ITS deployment and operations, which requires real-time data exchange and communications among distributed system components. The paper identifies different types of interoperability in the context of ITS. It examines a set of technologies that have emerged in recent years and discusses ways to utilize these technologies for ITS spatial data integration and interoperability.

Case for Unified Linear Reference System (32)

This paper makes the case for development of a unified linear reference system to accomplish better data integration across three functionally and institutionally distinct domains: transportation facility operators; civilian; and military transportation users. It discusses how each of these currently collects and maintains separate, often redundant or inconsistent information concerning the location and status of the transportation system, the vehicles using the system, and the passengers and freight (or material) being conveyed. It argues that although there has been some progress made in integrating data within each domain, little emphasis has been placed on identifying and improving the flow of information between them. Because activities initiated in one domain affect conditions in the others, defining these flows is crucial to the next generation of planners, traffic managers, and customers of transportation services.

Management System Integration Committee Report (33)

The goal of the former Management Systems Integration Committee (MSIC) was to help state and regional transportation agencies fully use the outputs of current management systems to support their decision-making process. A summary of the committee's findings was published in 1997. This report focuses on the application and integration of existing tools, and the applicability of these tools to each step of a transportation agency's business process including long-range planning, STIP/TIP development, program implementation, and operations. Examples in this report are drawn from current practices in state and regional agencies (Colorado, Florida, Michigan, Missouri, Oregon, Metropolitan Transportation Commission (MTC) in Oakland, California, and the Pima Area Council of Governments in Tucson, Arizona). This report also includes recommendations on establishing a common geographic referencing system.

NCHRP Project 8-32[5] – Guidance Manual for Managing Transportation Planning Data (34)

The scope of NCHRP Project 8-32[5], "Multimodal Transportation Planning Data," included the development of guidelines for assessing transportation data needs, and organizing and integrating data. NCHRP Report 401 summarizes the findings of this study. In the area of data integration, the report discusses institutional and technological challenges and general implementation strategies (e.g., centralized and decentralized approaches). The report also summarizes previous GIS research and presents several case studies that illustrate the data integration efforts of state DOTs (New Mexico, Michigan, Vermont, and Wisconsin) and local agencies (Bay Area Partnership, NCTCOG, Boston, Newton (Massachusetts), Atlanta, and Charlotte).

NCHRP Project 14-9[4] – Role of Highway Maintenance in Integrated Management Systems (35)

The objectives of NCHRP Project 14-9[4] were to define the next generation maintenance management system (MMS) based on data currently available at state DOTs and to provide guidance for implementation. The findings of this study are documented in *NCHRP Report 363*. The system presented in this report envisions a high level of integration between maintenance management systems and other DOT systems (e.g., bridge management systems (BMS), pavement management systems (PMS), financial systems, planning data, construction/project management systems, etc.). The report recommends a "hub-and-spoke" approach to developing an integrated MMS. In this approach, all data required for a particular organizational unit (which may include data from all the systems listed above) are located in a single hub. This hub also contains all necessary analytical capabilities required by the staff in the unit. The report also discusses the costs of data integration, alternative mechanisms for integration (e.g., manual sharing, data standards, combining systems, etc.), and hardware and software requirements.

Retrieving and Integrating Data from Multiple Information Sources Research Report (36)

With the current explosion of data, retrieving and integrating information from various sources is a critical problem. Work in multi-database systems has begun to address this problem, but it has primarily focused on methods for communicating between databases and requires significant effort for each new database added to the system. This paper describes a more general approach that exploits a semantic model of a problem domain to integrate the information from various information sources. The information sources handled include both databases and knowledge bases, but other information sources could potentially be incorporated into the system. The paper describes how the domain and the information sources are modeled, shows how a query at the domain level is mapped into a set of queries to individual information sources, and presents algorithms for automatically improving the efficiency of queries using knowledge about both the domain and the information sources.

Spatial Information and Modeling System for Transportation (SIMS) Final Report (37)

This document describes the development of a spatially based transportation information and modeling system called SIMS. The project and all software development were done in the Intergraph MGE environment. One objective was to investigate software tools for locating spatial data. A system called the Archival Management System (AMS) was developed to assist in the management of a spatial data archive. The AMS can manage data describing aerial photographs, satellite images, maps, or Intergraph design files.

Reasoning for Data Integration: Preparing for Construction in the 21st Century (38)

This paper discusses data communications requirements of an intelligent, automated construction planning system (OARPLAN) functioning in a prototype of a distributed, integrated computing environment (KADBASE). It addresses the need to improve inter-disciplinary communication of design and construction data. In addition to the basic problems of data integration, OARPLAN poses special requirements for accessing spatial, topological, and temporal information.

Additional General GIS References (39, 40, 41, 42)

There are many publications on GIS and transportation data integration methods. The Bureau of Transportation Statistics web site (www.bts.gov) lists several sources including the Geospatial One-stop initiative to create a core data content standard for transportation. Other published sources of information include the *Proceedings of the Annual GIS for Transportation (GIS-T) Symposium*, which has been held since 1988 (proceedings are available on the BTS web site through 2001). Recent relevant presentations from these proceedings are included throughout this white paper. Other sources include a collection of papers on *GIS-T Research* published in the journal Transportation Research in 2000, a collection of papers on *GIS Technologies for Transportation* published by URISA in 1999, a book of *Transportation GIS* case studies from ESRI in 1999, a book on *Geographic Information Systems for Transportation* by Harvey Miller and Shih-lung Shaw in 2001, and a collection of papers on *Geographic Information Systems and Transportation* in a special edition of the journal Transportation Planning and Technology in 1997.

■ State Transportation Agencies

Delaware’s Integrated Transportation Management System (43)

A recent newsletter of the National Associations Working Group (NAWG) for ITS Cooperative Deployment Network (ICDN) described Delaware DOT’s new integrated, multimodal transportation management system called Deltrac. A key feature of the

Deltrac system is an Oracle database with a web interface. The database stores transportation data from both legacy systems and new components, and allows DelDOT to perform both planning and real-time operations using a single database. All users can access the system through a uniform (Extensible Markup Language) XML-based interface from any computer with access to the web.

Iowa DOT Bridge Management Using Pontis® (44)

The Midwest Transportation Consortium's homepage describes a project to develop, implement, and operate an Integrated Bridge Asset Management System (IBAMS) for Iowa DOT. The project has the following objectives:

- Collecting and integrating bridge structural performance data;
- Developing a system to capture bridge visual inspection data; and
- Using the Pontis bridge management system to integrate these data sources into an IBAMS.

Ohio DOT's Base Transportation Referencing System (BTRS) (45)

This presentation describes an effort to develop Ohio DOT's Base Transportation Referencing System (BTRS). The BTRS integrates ODOT's GIS with 11 enterprise management systems including the Project Development Management System (PDMS), the Construction Management System (CMS), and the Pavement Management System (PMS).

Integrating Not Only Data Sets, But Also Business Relationships (46) and Integrating the Enterprise at Florida DOT (47)

This presentation discusses the concept of a geo-referenced information system that integrates diverse locational data from a variety of data sources within Florida DOT. The system is a spatially enabled web-based tool called the Geo-Referenced Information Portal (GRIP). The presentation also examines the pros and cons of data reengineering vis-à-vis preserving legacy information systems, and the technical and organizational issues faced while integrating informational systems with data from legacy infrastructure management systems.

An earlier presentation *Integrating the Enterprise at Florida DOT* (47) describes the development of Florida DOT's geo-referenced Enterprise Information Portal (EIP), an enterprise GIS system that is linked to legacy data and the agency's Electronic Document Management System (EDMS). The document also touches upon FDOT's use of a centralized GIS in order to address the challenges of maintaining multiple, specialized databases. The EIP also provides centralized access to FDOT data, and supports consistent data reporting across all district offices.

Oklahoma DOT's Intranet Portal (48)

The presentation describes the development of Oklahoma DOT's Geographical Resource Intranet Portal (GRIP), a GIS-enabled and web-based system that provides ODOT users access to enterprise transportation information.

Updating the Nebraska Department of Roads' Data Model for Enterprise GIS Applications (49) and Supporting a Geographic Transportation Database for Nebraska (50)

The presentation describes the development of a data model for GIS-enabled enterprise applications at the Nebraska Department of Roads (NDOR). The presentation addresses issues such as the management of graphics features, linear referencing systems, web-based access to data, etc.

Earlier work by the Nebraska GIS Steering Committee (NGISSC) (Supporting a Geographic Transportation Database for Nebraska (50) prioritized the development of a statewide geographic transportation database, and has tasked the Nebraska Department of Roads (NDOR) with preparing an action plan to accomplish the same. In addition, NDOR has hired a consultant to develop a GIS strategic plan. The following are some of the issues that these two plans are expected to address:

- Data warehousing and database technologies;
- Internet-based applications;
- Easily customizable, open-systems software; and
- Communication technologies for distributing this data.

Everyplace is Someplace: A Universal Location-Based Service at Delaware DOT (51)

The presentation describes Delaware DOT's efforts to provide a single geocoding and location-based services (LBS) point of processing for the entire state. The LBS supports addresses, GPS coordinates, and known points.

Transportation Framework for Washington State GIS Project (52)

The purpose of the Washington Statewide Transportation (WA-Trans) Framework Project, undertaken by the Washington DOT and supported by the Washington State Geographic Information Council (WAGIC) and the State Framework Management Group (SFMG) is to develop a transportation layer for Washington State. As per the project charter and the project executive summary, the transportation layer comprises a consistent and continuous set of cadastral, hydrographic, transportation, ortho-imagery, and topographic data sets for use in a GIS. The following are the objectives of the project:

- Identifying and recruiting partners to develop, maintain and distribute the transportation framework and the associated datasets;
- Developing a data model and establishing standards for the framework;
- Establishing institutional arrangements to facilitate data collection and dissemination; and
- Implementing software and processes to support integration of new data, data maintenance, and data access by partners and the general public.

It's All In There: NJDOT Manages Highway Maintenance (53)

This document describes efforts by the New Jersey Department of Transportation (NJDOT) to coordinate data collection and sharing efforts for its Traffic Engineering and Safety and Division of Operations Support offices. Working together, the two offices were able to successfully implement an integrated feature inventory.

New York State's Approach to Asset Management: A Case Study (54)

This paper describes New York State Department of Transportation's (NYSDOT) approach to asset management, which includes a data integration initiative. The paper stresses the importance of an effective organizational and business foundation for asset management to provide a focus for the technical elements. It describes efforts in four key areas:

1. Develop well-defined organizational roles within a highly decentralized department;
2. Design and implement a formal and disciplined core business procedure (the program update process) to cover program development and performance monitoring;
3. Develop transportation management systems for pavement, bridge, congestion, mobility and public transportation; and
4. Design and implement a state-of-the-art automated program and project management system that serves, in part, to integrate the department's use of the individual management systems, and maintains all essential data for developing and managing the program.

Linear Referencing System for Virginia DOT (55)

This presentation describes the definition and implementation of a NCHRP 20-27[3]-based Linear Reference System for Virginia DOT, to support the development of Virginia DOT's Inventory Condition and Assessment System (ICAS). The ICAS system makes use of Oracle database application along with ESRI GIS technology to provide a fully spatially enabled solution. It also enables the distribution of non-spatial DOT information through a web-based mapping system that is currently being implemented.

Enterprise Data Model at the Idaho Transportation Department (56, 57)

This presentation describes the process of developing an information strategy plan and an enterprise data model (ISP/EDM) for the Idaho Transportation Department (ITD). The model includes the following:

- Business practices and procedures;
- Data used or produced by production processes;
- Data used to control, monitor, or manage production operations; and
- Data drawn from the above for distribution to the public.

An earlier report *Making Data Simply Visible: Idaho Transportation Department Information Strategy Plan and Enterprise Data Model* (57) was a strategy plan for the Idaho DOT providing an enterprise-wide strategic vision guiding the next generation of data management, systems development, and technology deployment decisions.

Pennsylvania DOT's GIS Technical Report (58)

The report provides a detailed description of Pennsylvania DOT's GIS, and provides a history of its development. The report also serves as a technical manual for GIS-T database design and development. PennDOT's GIS integrates the following systems:

- Roadway Management System (RMS);
- Bridge Management System (BMS);
- Maintenance Operation Research Information System (MORIS);
- Multimodal Project Management System (MPMS);
- Crash Records System (CRS);
- Traffic Monitoring Sites Maintenance System (TMS);
- Intermodal System (IMS);
- Railroad database; and
- Cultural resources database.

Coordinated Data System for Hawaii DOT (59)

A brief note on the Intergraph Corporation's web site describes the development of a Coordinated Data System/Geographic Information System (CDS/GIS) for Hawaii DOT. CDS/GIS is an enterprise-wide information system that integrates highway inventories, traffic data, pavement data, projects, bridge data, and reports into an Oracle database. CDS/GIS applications include a pavement management system, a bridge management system, a congestion management system, a safety management system, a public transportation system, an intermodal system, a traffic monitoring system, and a finance system. Prominent features of the system include the following:

- Standard reference system and common user interface;
- Statewide access to data; and
- Integration with external data sources, such as the National Bridge Inventory (NBI).

GPS to LRM: Integration of Spatial Point Features with Linear Referencing Methods (60)

In 2001 the Iowa DOT participated in a pilot study in order to identify the issues associated with the integration of GPS data with a linear referencing method (LRM). This report documents the findings of this study and recommends ways of overcoming fundamental differences in the collection, manipulation, and integration of data within these two systems. Key issues addressed in this report include:

- Mapping of point features onto incorrect segments;
- Spatial information lost in transferring a two-dimensional or three-dimensional point feature onto a one-dimensional LRM;
- Lack of spatial accuracy in the cartography on which most LRMs are based; and
- Transferring point feature data between LRMs.

Enterprise GIS for Virginia DOT (61)

This presentation covers the following topics related to the development of Virginia DOT's Enterprise GIS:

- Integration of data from VDOT legacy systems and limitations;
- The role of web and fat client products;
- Management of large volumes of image data;
- Considerations for hosting large volumes of spatial and image data; and
- Metadata and other technical data.

Minnesota DOT Method for Linear Location (62)

This presentation describes Minnesota DOT's efforts to develop a Location Data System to provide transportation management systems access to centrally managed location information. The system will allow for the collection and maintenance of location data and provide location integration and conversion services. It is anticipated that this system will become the foundation for other computer applications used to locate, integrate, and analyze transportation data using different referencing systems.

Building a Common Centerline to Serve State and Local Government (63)

This presentation describes the development of a common street centerline file by Virginia DOT and the Fairfax County Geographic Information Services Department, to support both county-level applications (e.g., routing of emergency vehicles) and state-level applications (e.g., pavement management systems). It also highlights the applications supported by such a data set and the benefits of using a more advanced data model.

Using TRIMS as a Decision Support Tool (64)

This presentation describes the use of the Tennessee Roadway Information Management System (TRIMS) as a decision support tool to aid in asset management. TRIMS integrates roadway information with pavement information, and produces reports on the condition of infrastructure assets such as highways and bridges. Useful capabilities of the model include the following:

- Federal reporting requirements for roads and their associated assets;
- Support for multiple linear referencing methods (LRM);
- Provision of dynamic segmentation for event data; and
- Support for a complete historical record of Transportation Information System (TIS) data.

System Design of GIS for Illinois DOT (65, 66)

Presentations by Hall et al. (2000) and Lindquist (1999) describe Illinois DOT's use of a stable roadway node-link base as an interface for integrating all roadway-related information drawn from a diverse set of legacy databases. The strategy allows IDOT to provide multiple and disparate references to the GIS base including several route/milepost schemes, various project tracking numbers, and structure/rail crossing identifiers.

The Development of a Full Digital and Networkable Multimedia-Based Highway Information System (67)

This document describes the use of video log technologies to capture and integrate highway data in Arkansas. Roadway video logging has been in use for more than a decade, with several commercial systems on the market. The existing systems use analog data displays together with GIS to match the images with road location. The authors describe a digital-based system that integrates several components in a multimedia application, including GIS, database and image library.

GIS Strategic Plan for Kansas DOT (68)

The report presents an updated strategic plan for GIS at Kansas DOT, to support the Comprehensive Transportation Program (CTP) initiative currently being implemented at KDOT. Other strategic initiatives include the following:

- Integrating GIS with other emerging technologies such as GPS, video logging, and ITS, etc.;
- Supporting location referencing methods (GPS/XY coordinates, addresses, etc.) in addition with standard Linear Referencing System (LRS); and
- Using GIS to integrate transportation data.

GIS Tools for Minnesota DOT's Transportation Information System (TIS) (69)

This presentation describes a GIS application called TIS-GIS that can be used to access and view data from Minnesota DOT's new Oracle-based Transportation Information System (TIS). The application was developed using ArcView, and provides a tool for data querying, analysis, mapping and reporting.

Integrating Bridge Management Systems into the Business Process and Software Environment of the State DOT: Three States' Experiences (70)

This paper reviews experiences from three states (California, Michigan and Mississippi) related to integration of Pontis bridge management system (BMS) with broader transportation management systems (TMS) in place. For each state, approaches to development of data schemas, data sharing, data flows across systems, and integration challenges are discussed.

Integration of Bridge and Pavement Management Systems: A Proposed Strategy for Asset Management (71)

This paper developed by the FHWA and the Colorado DOT outlines a framework for an integrated asset management approach that permits the comparison of outputs from pavement, bridge, and other asset management systems, and enables the allocation of funds across different asset types. The paper identifies performance measures that can be compared across asset types (e.g., agency costs, user costs, safety, mobility, environment, quality of ride, and relative use of the system), provides guidance on developing these measures for pavements and bridges, and describes how these measures can be rolled up and applied within an integrated asset management approach.

Integrated Transportation Design for Highway Projects (72)

The New Mexico State Highway and Transportation Department, in cooperation with the FHWA, produced a report that outlines the concept of Integrated Transportation Design (ITD). The report identifies knowledge management as an integral component of good asset management. It defines knowledge management as the management of information flow to ensure that the right information is received by the right people. It identifies the following key characteristics of good knowledge management:

- Full access, when required, to the raw data;
- Asynchronous and dispersed involvement;
- Extended historical perspective; and
- Integration into the design process instead of reliance on a single feedback loop.

A Network Model to Support Enterprise-wide Data Sharing (73)

This presentation describes the development and testing of a road data model, a core component of Georgia DOT's enterprise-wide Transportation Information System (TIS). Key features of the data model include the following:

- An anchor section-intersection-based model;
- Support for multiple linear referencing methods (LRM);
- Provision of dynamic segmentation for event data; and
- Support for a complete historical record of TIS data.

Iowa DOT Statewide Coordinated GIS (74)

This presentation describes Iowa DOT's use of GIS tools to integrate data from several database systems throughout the organization. A single interface was developed that allows cross-system data queries and map display, and allows end users unfamiliar with the underlying data structures to access this data. The presentation also explores strategies for system maintenance, and additional integration (e.g., use of GPS for data collection) as the system matures.

Enterprise Spatial Information Access Application at New Mexico SHTD (75)

This presentation describes an Intranet Decision and Analysis Support System (IDEAS) developed by the New Mexico Highway and Transportation Department (NMSHTD). IDEAS uses the spatial indexing capability of data collected by the planning group of the NMSHTD (including the road network, pavement conditions, bridge inspection reports, accident statistics, etc.), all of which can be tied to the road network through a linear referencing system. The system provides a web-based solution that integrates planning, design, and maintenance information systems, and thus supports multiple decision-making processes.

Database Design for GIS in North Carolina DOT (76)

The presentation describes the process of designing a database to store attribute data for North Carolina DOT. The design allows data access using NCDOT's newly established Linear Referencing System (LRS), through both GIS and non-GIS Relational Database Management System programs.

Civil Engineering Data Integration System (CEDIS) at Florida DOT (77)

This presentation describes ongoing work on Florida DOT's Civil Engineering Data Integration System (CEDIS), a system that collects, stores, updates, analyzes, and displays geographically referenced information acquired during the design, construction and maintenance of the FDOT's transportation facilities. Coupled with a suitable base map, this vendor-neutral system can provide data relating to the construction and management of FDOT's assets to a broad audience.

A System to Support Data Integration (78)

A 1997 report prepared by the South Dakota DOT Office of Research describes the methods of transforming data between regular coordinates and linear referencing methods and vice versa. Like many States, SDDOT supports several location referencing methods including geodetic coordinates using GPS, mile marker references, and station offset measures. The report reviews these methods and makes recommendations on how the different locations can be translated via a common coordinate referencing system. The report also discusses the issues involved in transforming GPS coordinates into linear features.

Improvements to Utah's Location Referencing System to Allow Data Integration (79)

A location reference "system" and a location reference "method" are distinguished by listing options available for location reference methods and explaining the importance of a standardized system to facilitate integrating data from more than one source. The conclusion describes necessary changes to Utah DOT's method and the implementation procedures necessary to stabilize and improve Utah's system to meet the objective of data integration. Both linear and spatial approaches to location referencing are discussed. However, the focus is on explaining the details of the four basic linear methods, including advantages and disadvantages of each. Issues the Utah DOT needed to address when it selected its approach to location referencing are presented, including:

- Balance between system and method;
- Stability of addresses;
- Procedures to accommodate address changes;
- Ability to replace one unit of measure with another; and
- Institutional issues and training requirements.

Local Transportation Agencies

Integration Broadens Appeal of GIS Data (80)

An article Federal Computer Week (FCW) Media Group's web site discusses state and local government's use of GIS for integrating data from disparate sources, and disseminating it to the general public. The article highlights difficulties faced in integrating road, weather, traffic, financial, and other organizational data into GIS applications, and in integrating these applications with commercial off-the-shelf products. Examples of successful integration efforts include: San Diego Transportation Department's integration of financial, organizational and public works data within a GIS.

Road Management System for Local Governments (81)

The Midwest Transportation Consortium's homepage describes a project to develop the decision framework for a Road Management System (RMS), and produce a manual to guide transportation agencies attempting to integrate modular pavement, bridge, and sign management systems.

Methodology for Achieving GASB 34 Modified Approach Compliance Using Navy 'Smart Base' Facility Management Practices (82)

This research develops a strategy and methodology for small local governments to create flexible, cost-effective asset management systems. Faced with the management of a global infrastructure portfolio exceeding $130 billion in 2001, the U.S. Navy has invested heavily in the area of public works management. The Smart Base project at Naval Shipyard Portsmouth, an ongoing initiative to develop customized information technology solutions at the installation level, is examined as a model for small towns to emulate during the development of GASB 34 compliant asset management systems. The resultant methodology provides a simple, robust framework for the integration of inventory, condition and valuation data within the existing GIS system used by the town of Winchester, Massachusetts.

TCRP Project J-07 – Information Technology Update for Transit (83, 84)

The scope of Transit Cooperative Research Program Project J-07 "Synthesis of Information Related to Transit Problems" included TCRP Synthesis 35, an update to *TCRP Synthesis 5* which is summarized below. TCRP Synthesis 35 documents the transit industry's state–of-the-practice in information and communications technologies, and focuses on Information Technology practices in large transit agencies. The project included a survey of over 30 transit agencies. The report states that the United States transit agencies are behind the state-of-practice in IT, but that improvements had been made since the 1994 study. The report presents the findings of the surveys organized around the following areas:

- Management architecture;
- Application architecture;
- Technical architecture; and
- ITS/APTS architecture.

Of these, survey participants indicated that the management architecture was the most critical component of an IT plan. The study also concluded that of the available support technologies, data warehousing has had the greatest impact on an agency's data integration efforts.

A related project, *TCRP Project J-7 Management Information Systems* (84) included synthesizing the state-of-the-practice in information systems among transit agencies, documenting barriers to implementation, and identifying critical success factors. The results of this study have been documented in *TCRP Synthesis 5.* This report summarizes and synthesizes current practices by several transit agencies (Bay Area Rapid Transit, MTA New York City, Seattle Metro, Toronto Transit Commission, and Metropolitan Atlanta Rapid Transit Authority). Key focus areas in the report are 1) the integration of special purpose systems into an agency's overall suite of information systems, and 2) the degree of overall system integration among transit agencies. The report identified nearly 20 activities that were most important for enhancing an agencies IT environment including institution of an agencywide IT planning process, decentralizing access to management systems, migration towards an open architecture, establishment of a helpdesk, and moving towards off-the-shelf software rather than custom applications.

Data Integration between Multiple Counties for Regional Planning and Trans-Boundary Linear Referencing (85)

This document provides information in the following categories: Puget Sound Regional Council (PSRC) membership and population served; PSRC GIS strategy; primary project goals for better transportation data sharing; typical format of a traffic event for a city; and PSRC integration of disparate transportation data.

Columbia, Missouri Case Study (86)

This case study describes an effort by the city of Columbia, Missouri to integrate data from its legacy pavement management system into a maintenance management system provided by Hansen Information Technologies. The resulting system is an integrated infrastructure asset management system that contains a complete inventory of street segments, traffic signals, street signs, pavement markings, stormwater facilities, equipment, vehicles, materials, and employee records. The system is capable of generating cost analyses reports for more than 8,000 scheduled activities performed by Street, Stormwater, Maintenance, and Traffic Divisions. A review by an external auditing firm also deemed the system capable of providing cost and asset data required to become compliant with the Governmental Accounting Standards Board (GASB) Statement 34.

Summary

Table 1 summarizes the key aspects of the above referenced documents. The following information is provided for each document:

- Source and reference number containing the full citation for the document;
- Aspect of data integration being addressed (data architecture, location referencing, or organizational issues);
- The type of data addressed in the document; and
- The agencies involved in the data integration efforts.

This extensive literature search reveals that there is a great deal of activity occurring in public agencies with respect to all aspects of data integration. The syntheses and peer exchange summaries will be particularly helpful in the identification of best practices of data integration for asset management throughout the remainder of this project.

Sources reviewed include a wealth of information on the benefits of data integration in support of asset management, the key activities that are important to successful data integration efforts, technical approaches and methods, as well as barriers to be overcome

Table 1. Document Summary

Source (Reference Number)	Data Architecture	Location Referencing	Organizational Issues	Type of Data	Applications/Implementations
A GIS-T Approach to Integrating Asset Management and Maintenance Management (1)	X			GIS data, maintenance management system data	NA
NATMEC Presentation on Integration of Data Sources (2)			X	General transportation data	NA
Cost and Benefits of Using ITS as an Alternative Data Source (3)	X		X	ITS data	NA
Asset Management Model and Systems Integration Approach (4)	X		X	Asset management system data	NA
Achievements of the DOT-NASA Joint Program on Remote Sensing and Spatial IT (5)		X		Satellite images, aerial photos, and LIDAR 3-D images	Brief examples of state-of-the-practice at Iowa DOT, and Wisconsin DOT
Collecting, Processing, and Integrating GPS Data into GIS (6)	X	X		GPS data, GIS data	Survey results from 27 DOTs (Alaska, Arizona, Connecticut, Delaware, Florida, Georgia, Hawaii, Kansas, Louisiana, Maryland, Maine, Michigan, Mississippi, Montana, Nebraska, New Hampshire, North Dakota, New York, Oklahoma, Oregon, Pennsylvania, Tennessee, Utah, Washington, West Virginia, and Wyoming) and three regional agencies (CATS, Metro Wash COG, and SEMCOG), and detailed examples for two DOTs (Oregon and Tennessee).
The Role of GIS in Enterprise Data Sharing Frameworks (7)		X		GIS data, general transportation data	Examples from British Columbia
Using Location to Integrate Local and State Government Road Information (8)		X		Spatial data	Examples from the City of Rochester and Olmstead County, Minnesota
Integrating and Using Highway Dynamic Data with Relatively Infrequently Published GIS Data (9)		X		GIS data, dynamic transportation data	NA
Spatial Solutions for Document and Information Management (10)	X	X	X	GIS data, electronic documents	NA
TRB Peer Exchange on Integrating Highway Information (11)	X	X	X	General transportation data	Detailed status reports from eight DOTs (Florida, New York, Virginia, Maine, Minnesota, Kansas, Michigan and Wisconsin), two regional agencies (Pima Association of Governments, Baltimore Metropolitan Council), and one city (Jacksonville, Florida)

Table 1. Document Summary (continued)

Source (Reference Number)	Data Architecture	Location Referencing	Organizational Issues	Type of Data	Applications/Implementations
FHWA Forum and Peer Exchange on Data Integration for Asset Management (12)	X	X	X	General transportation data	Detailed status reports from seven state DOTs (Florida, Maine, Michigan, Mississippi, Ohio, Tennessee, and Virginia)
Asset Management Guidance for Transportation Agencies (13)	X	X	X	Inventory, condition, financial, system needs, and project data	Brief examples from seven DOTs (New York, Michigan, Arizona, Colorado, Pennsylvania, Washington, and California)
FHWA Data Integration Primer (14)	X	X	X	General transportation data	Brief highlights of current practices from six DOTs (Mississippi, Tennessee, Virginia, Michigan, Maine, and Florida)
TRB Peer Exchange – Enhancing the Value of Data Programs (15)	X	X	X	General transportation data	Detailed status reports from eight DOTs (Minnesota, Texas, Kentucky, Montana, Michigan, Florida, California, and New York)
Application Sharing: Best Practices and Lessons Learned (16)	X		X	Transportation, GPS, finance, and Administration data	Examples from three state DOTs (Washington, Michigan, and Vermont), and three state governments (Arkansas, Georgia, and Pennsylvania)
Guidelines for the Implementation of MDLRS (17, 18)		X		MDLRS data model	NA
Data Warehouse Considerations in GIS-T (19)	X	X	X	GIS data, general transportation data	Examples from state DOTs (which ones?)
NSDI Framework Transportation Identification Standard (20)		X		TIGER/Line files, Digital Line Graph Files, National Highway Planning Network, and general state transportation data	NA
A Data Foundation for the National Spatial Data Infrastructure (21)	X	X		Spatial data	NA
Implementation of an Executive Information Management System (22)	X			GIS data, spatial data	Description of an information system for the Pennsylvania Turnpike Commission's (not part of DOT)
Asset Management Peer Exchange: Using Past Experiences to Shape Future Practice (23)			X	NA	Examples from state DOTs (New York, Minnesota, Virginia, Montana, and Michigan)
Spatial Data Handling for ITS: Perspective, Issues and Approaches (24)	X	X			NA
GIS-T as an Integral Component of ITS (25)		X		GIS data, ITS data	NA

Table 1. Document Summary (continued)

Source (Reference Number)	Data Architecture	Location Referencing	Organizational Issues	Type of Data	Applications/Implementations
Object-Oriented Network Data Structures (26)	X	X		GIS data	NA
Transportation Design Meets Transportation GIS: Sharing a Common Database (27)		X		GIS data, CAD data	NA
Geographic Information Systems for Transportation – A Look Forward (28)	X	X	X	General transportation data	NA
Information Technology in Transportation – Key Issues and a Look Forward (29)	X			General transportation data	NA
Development of Prototype Highway Asset Management System (30)	X			Highway asset data	NA
Spatial Data Integration and Interoperability for ITS (31)	X	X		GIS data, ITS data	NA
Case for Unified Linear Reference System (32		X	X	LRS data	NA
Management System Integration Committee Report (33)		X	X	Output from transportation systems	Brief examples from five DOTs (Colorado, Florida, Michigan, Missouri, and Oregon), and two regional agencies (Metropolitan Transportation Commission in Oakland, California, and the Pima Area Council of Governments in Tucson, Arizona)
Managing Transportation Planning Data (34)	X	X	X	Supply attributes, demand attributes, system performance, and system impacts	Brief case studies of four DOTs (New Mexico, Michigan, Vermont, and Wisconsin), two regional agencies (Bay Area Partnership, and NCTCOG), and three cities (Boston and Newton, Massachusetts, Atlanta, Georgia and Charlotte, North Carolina)
Role of Highway Maintenance in Integrated Management Systems (35)	X	X	X	Highway maintenance data, data from asset management systems (BMS, PMS, etc.), financial data, planning data, project data, permits, etc.	NA
Retrieving and Integrating Data from Multiple Information Sources (36)	X			NA	NA
Spatial Information and Modeling System for Transportation (SIMS) Final Report (37)		X		GIS data, aerial photographs, satellite images	NA

Table 1. Document Summary (continued)

Source (Reference Number)	Data Architecture	Location Referencing	Organizational Issues	Type of Data	Applications/Implementations
Reasoning for Data Integration: Preparing for Construction in the 21st Century (38)	X			Spatial data, general construction data	NA
Additional General GIS References (39, 40, 41, 42)		X		GIS data	NA
Delaware's Integrated Transportation Management System (43)	X			General transportation data	Examples from Delaware DOT
Iowa DOT Bridge Management Using Pontis (44)	X			Bridge management system data	Examples from Iowa DOT
Ohio DOT's Base Transportation Referencing System (45)	X			GIS data, enterprise management system data	Examples from Ohio DOT
Integrating Not Only Data Sets, But Also Business Relationships (46)	X		X	GIS data, spatial data, asset management system data	Examples from Florida DOT
Integrating the Enterprise at Florida DOT (47)	X			GIS data	Examples from Florida DOT
Oklahoma DOT's Intranet Portal (48)	X			GIS data, general transportation data	Examples from Oklahoma DOT
Updating the Nebraska Department of Roads' Data Model for Enterprise GIS Applications (49)	X	X		GIS data	Examples from Nebraska DOT
Supporting a Geographic Transportation Database for Nebraska (50)	X	X	X	GIS data	Description of a strategic plan for the Nebraska statewide geographic transportation database
Universal Location-Based Service at Delaware DOT (51)		X		Spatial data	Examples from Delaware DOT
Transportation Framework for Washington State (52)	X	X	X	GIS data, cadastral data, hydrographic data, general transportation data, ortho-imagery data, and topographic data	Examples from Washington DOT
It's All In There: NJDOT Manages Highway Maintenance (53)	X		X	General transportation data	Examples from New Jersey DOT

Table 1. Document Summary (continued)

Source (Reference Number)	Data Architecture	Location Referencing	Organizational Issues	Type of Data	Applications/Implementations
New York State's Approach to Asset Management (54)	X		X	Asset management system data	Examples from New York DOT
Linear Referencing System for Virginia DOT (55)		X		LRS data, GIS data	Examples from Virginia DOT
Enterprise Data Model at the Idaho Transportation Department (56)	X			Production process data, production operations data	Description of work at Idaho DOT
Idaho Transportation Department Information Strategy Plan and Enterprise Data Model (57)			X	NA	Description of a strategy plan for the Idaho Transportation Department
Pennsylvania DOT's GIS Technical Report (58)	X	X		GIS data, asset management system data, general transportation data	Examples from Pennsylvania DOT
Coordinated Data System for Hawaii DOT (59)	X	X		GIS data, pavement data, bridge data, project data	Examples from Hawaii DOT
GPS to LRM: Integration of Spatial Point Features with Linear Referencing Methods (60)		X		GPS data, LRM data	Pilot study in Iowa DOT
Enterprise GIS for Virginia DOT (61)	X			GIS data, image data	Examples from Virginia DOT
Minnesota DOT Method for Linear Location (62)	X			General transportation data, spatial data	Examples from Minnesota DOT
Building a Common Centerline to Serve State and Local Government (63)	X	X		Spatial data	Description of a joint effort by Virginia DOT and Fairfax County
Using TRIMS as a Decision Support Tool (64)	X			Roadway data, pavement data	Description of a system at Tennessee DOT
System Design of GIS for Illinois DOT (65, 66)		X		Spatial data	Examples from Illinois DOT
Development of a Full Digital and Networkable Multimedia-Based Highway Information System (67)	X	X		GIS data, Multimedia data	NA
GIS Strategic Plan for Kansas DOT (68)		X	X	GIS data, LRS data, general transportation data	Examples from Kansas DOT
GIS Tools for Minnesota DOT's Transportation Information System (69)		X		GIS data	Description of system at Minnesota DOT

Table 1. Document Summary (continued)

Source (Reference Number)	Data Architecture	Location Referencing	Organizational Issues	Type of Data	Applications/Implementations
Integrating Bridge Management Systems into the Business Process and Software Environment of the State DOT (70)	X		X	Bridge management system data	Examples from three state DOTs (California, Michigan, and Mississippi)
Integration of Bridge and Pavement Management Systems: A Proposed Strategy for Asset Management (71)	X		X	Outputs from BMS and PMS	NA
Integrated Transportation Design for Highway Projects (72	X			General transportation data	NA
Network Model to Support Enterprise-wide Data Sharing (73)	X	X		GIS data, road data	Examples from Georgia DOT
Iowa DOT Statewide Coordinated GIS (74)	X	X		GIS data	Examples from Iowa DOT
Enterprise Spatial Information Access Application at New Mexico SHTD (75)	X	X		GIS data, roadway data, pavement data, bridge data, accident data	Examples from New Mexico SHTD
Database Design for GIS in North Carolina DOT (76)	X	X		Attribute data	Examples from North Carolina DOT
Civil Engineering Data Integration System at Florida DOT (77)	X			GIS data, design data, construction data, maintenance data	Examples from Florida DOT
System to Support Data Integration (78)		X		Spatial data, LRS data	Examples from South Dakota DOT
Improvements to Utah's Location Referencing System to Allow Data Integration (79)		X		Spatial data, LRS data	Description of a study conducted at Utah DOT
Integration Broadens Appeal of GIS Data (80)	X	X		GIS data, road data, weather data, traffic data, financial data, other organizational data	Examples from San Diego
Road Management System for Local Governments (81)	X			Roadway management system data	NA

Table 1. Document Summary (continued)

Source (Reference Number)	Data Architecture	Location Referencing	Organizational Issues	Type of Data	Applications/Implementations
Methodology for Achieving GASB 34 Modified Approach Compliance Using Navy 'Smart Base' Facility Management Practices (82)	X	X		GIS data, asset management system data	Proposed system for a town (Winter, Massachusetts)
Information Technology Update for Transit (83)	X		X	Planning, financial, safety, and engineering data	Survey of 30 transit agencies, and detailed examples from three transit agencies (MTA New York City, Port Authority of New York and New Jersey, and the Ann Arbor Transportation Authority)
Management Information Systems (84)	X	X	X	General transit data	Detailed examples from five transit agencies (Bay Area Rapid Transit, MTA New York City, Seattle Metro, Toronto Transit Commission, and Metropolitan Atlanta Rapid Transit Authority)
Data Integration between Multiple Counties for Regional Planning and Trans-Boundary Linear Referencing (85)	X	X		GIS data, general transportation data	Examples from the Puget Sound Regional Council
Columbia, Missouri Case Study (86)	X		X	Inventory and cost information for streets, traffic signals, street signs, pavement markings, stormwater faculties, equipment, vehicles, materials, and employees.	Description of a project conducted in Columbia, Missouri

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Task 2 – Detailed Reviews of Data Integration Practices

■ Overview

This section contains detailed descriptions of data integration activities in various transportation agencies. Twenty-seven agencies at the state and local level were selected from those identified in the general literature search, as well as knowledge about other agencies, and more detailed information concerning their data integration efforts was obtained. Some agencies were chosen specifically to look at how they intend to use integrated data for Transportation Asset Management. While all reviews highlight data integration activities that support Asset Management, they also describe integration efforts to support other agency applications including planning, operations, and ITS. They provide a broad range of approaches to addressing technical and institutional issues surrounding data integration. Finally, they provide an excellent base of information that can be used for case studies and to identify innovative data integration practices.

■ Background

Experience indicates that a large percentage of data integration projects fail or are not completed; clearly, there are significant technical and organizational issues and challenges associated with successfully integrating data.

The detailed reviews aim to identify potential approaches to overcoming these challenges and addressing a national, unmet need for information on innovative methods and best practices for data integration. They also provide an excellent base of information that can be used for future development of more detailed case studies.

Each review consists of five parts: 1) History/Background; 2) Integrated Data Considerations; 3) Integrated Data Architecture; 4) Lessons Learned; and 5) Future Plans. Information provided in the reviews includes:

- The incentive for data integration and how the initiative evolved in the agency;
- Types and attributes of data being integrated;
- Applications and agency functions to be supported by integrated data;
- Systems used to reference location and other data attributes;
- Software, hardware, and data management tools adopted to facilitate data integration;
- Technical and organizational hurdles;
- Innovative methods and strategies used to overcome the technical and organizational hurdles;

- Relationship of the data integration effort to the agency's Asset Management process; and
- Future plans for data integration to support Asset Management.

Agencies

Twenty-four state transportation agencies, one transit agency (New York Transit Authority), and two local transportation agencies (Columbia, Missouri and Puget Sound Regional Council Washington) were selected for detailed reviews. The state agencies are Alaska, Arizona, California, Colorado, Delaware, Florida/Florida Turnpike, Hawaii, Iowa, Kansas, Maine, Michigan, Minnesota, Montana, New Mexico, New York, Ohio, Pennsylvania, South Carolina, Tennessee, Utah, Vermont, Virginia, and Washington.

Information related to each agency's data integration activities was compiled mostly from electronic literature searches, agency websites, and interviews with agency staff. Each review does not necessarily address all data integration initiatives in the agency. Specifically, for those agencies that have multiple data integration efforts, the initiative chosen for detailed review was that which is most relevant to Asset Management. A contact person was also identified in each agency to provide input and feedback on the study.

State Agencies

Alaska DOT&PF Comprehensive Maintenance Management System

History/Background

The Alaska Department of Transportation and Public Facilities (ADOT&PF) does not have legislation in place to mandate Asset Management, but the agency has a strong interest in implementing an Asset Management program.

ADOT&PF's Asset Management program was developed out of a 2001 Comprehensive Maintenance Management System (CMMS) Feasibility Study. The Department is using the CMMS study, which recommends the development of a Maintenance Management System (MMS) as the framework for implementing Asset Management. Therefore, this detailed review focuses on the development of the MMS and its relationship to other databases in the Department.

The MMS will focus on traditional maintenance planning, budgeting, and resource management for the statewide multimodal transportation system. A pilot MMS will be implemented in spring 2004 and full statewide deployment is planned for late 2004. The pilot MMS inventory will be limited to a number of asset types. The Division of Maintenance and Operations (M&O), in association with Booz Allen and Hamilton, is leading the MMS development.

The Statewide Planning office has been emphasizing the need for improved data integration within the Department. They recognized there are currently no standards or methods to display data. It also takes a long time to find data within the Department. Therefore, the Statewide Planning Office is developing an interface that will link the Department's MMS with other transportation databases. As part of this effort, a data integration partnership was formed between the M&O Division and Planning Offices.

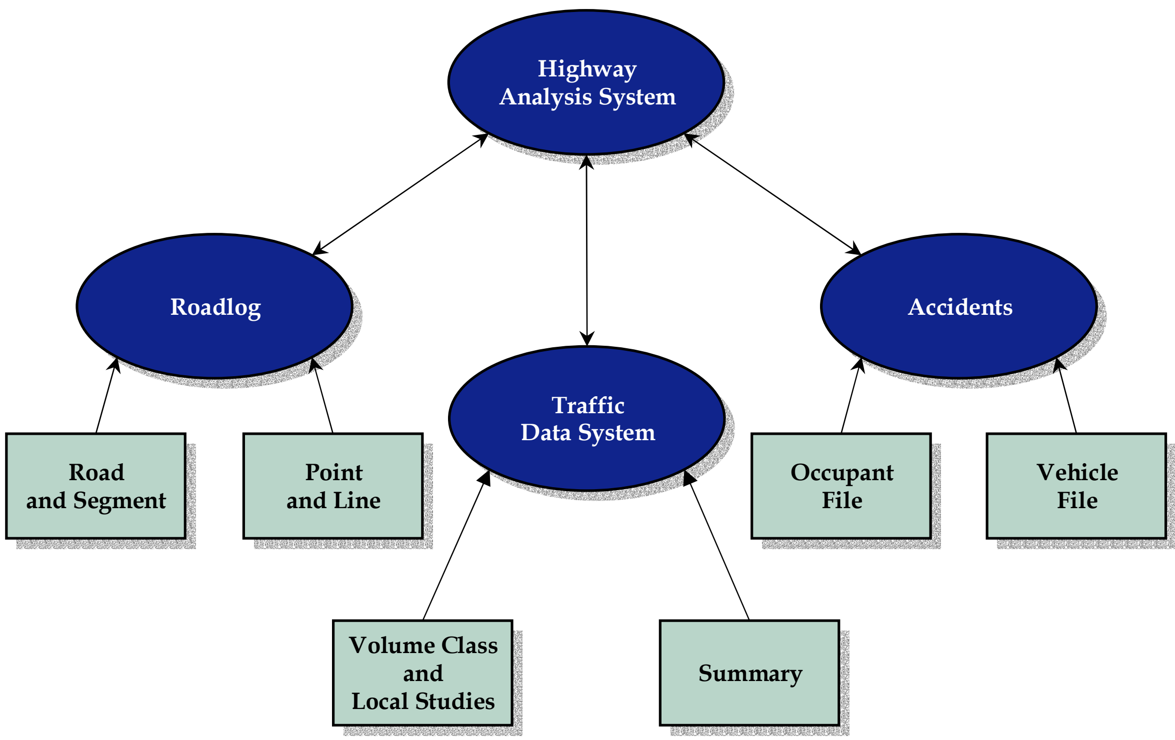
Under this initiative, the MMS will link with seven of Alaska's legacy databases, including ADOT&PF's transportation database and Highway Analysis System (HAS). The MMS also will integrate with other existing systems managed by the Statewide Planning Office including the Road Weather Information System (RWIS), the Alaska Traveler Information System (ATIS), and the statewide Geographic Information System (GIS).

The Highway Analysis System (HAS) will be the primary archive for MMS data. HAS contains road network data, highway features, and other transportation data such as traffic counts, vehicle crashes, and pavement conditions. Statewide Planning and M&O jointly established the data definitions and standards for the data fields that will support the MMS. The HAS and MMS will link with a data element key which will allow for both linear (route-milepoint) and coordinate-based reference systems.

■ Integrated Data Considerations

The Highway Analysis System integrates traffic, accident, and road network information. Figure 1 illustrates the related components.

Figure 1. Highway Analysis System (HAS) and Related Components



The Highway Analysis System is ADOT&PF's multi-component, hierarchical, mainframe legacy transportation database. Boeing Computer Services developed it in the late 1980s. HAS is coded in Natural programming language and uses ADABAS as the database manager. Both HAS application software and ADABAS files reside on an IBM mainframe in the Juneau Data Center (JDC). The Alaska Department of Administration's Information Technology Group operates JDC. Users access HAS through the Alaska Computer Network, which is available to all state agencies and other organizations with a link to the state's computer network. There is a generic user access to HAS reports and online queries. Access to batch reports, maintenance, and confidential information is user-id controlled.

Roadlog is the linear reference component of HAS and the backbone of the system. It defines the linear structure of the state road network, manages the political/geographic attributes for each road segment including roadway feature locations, and attributes (point and line features). Roadlog employs a route node linear reference system. Most users interact with Roadlog using a route-milepoint linear reference method; each road is represented by a unique Coordinated Data System route number (CDS route number) and locations along a given CDS route are described either with a single milepoint value or from/to milepoint values.

Integrated Data Architecture

As of 2001 when the MMS project started, most of the State's core systems ran in a main-frame environment. A networked, centralized, thin client environment will be created for the MMS. Oracle is the database of choice in Alaska. The State still maintains a wide area network (WAN) with hubs in Anchorage, Fairbanks, and Juneau.

Statewide Planning is collecting the MMS pilot project asset inventory and providing an MMS data archive. The HAS asset inventory and road network data will be exported to an Oracle relational database to support MMS reporting. Statewide Planning will develop the HAS online query capability and customized asset reports to support the MMS. Statewide Planning also is developing a comprehensive GIS that will fully integrate with the MMS when deployed in three to five years. Upgrades will focus on the Roadlog and GIS components of HAS. The long-term goal of the process is to integrate GIS technology with HAS to improve data access, display, analysis, and output. Upgrades to HAS will enable it to serve as the foundation for linear reference-based GIS within the Department. The objective of the HAS–GIS Interface Project is to develop targeted HAS–GIS upgrade strategies that can be implemented in three to five years and will:

- Improve data access, display, analysis, and output;
- Unify the processing, management, maintenance, and output of Roadlog and the road centerline network data in an integrated system; and
- Establish HAS as a foundation for linear reference system-based GIS within the Department.

Also proposed is a real-time HAS linkage that will allow M&O personnel to update asset information through a GIS interface.

Lessons Learned

The following four key issues impacted data integration for the MMS pilot and full-scale deployment:

1. Multiple Data Collection Projects – Statewide Planning will integrate the new MMS requirements into the existing highway inventory project.

2. Multiple Reference Systems – Planning uses route-milepoint while M & O uses route-milepost. Alaska's highways are missing mileposts and not all state routes have mile-posts. Additionally, the interval between the historic mileposts is almost never a mile.

3. GIS Development – The Department is working on unifying the processing, manage-ment, output of road features, and centerline network into a single integrated system with full capability in three to five years.

4. Management Commitment: Commitment is needed to continue funding field data collection equipment acquisition, data collection contracting, data processing and stor-age hardware/software procurement, and GIS development (funding and personnel resources).

Four key issues impacted the data definition and standard development for the MMS inventory items:

1. Working group knowledge about other participants' specialty areas. For example, Planning had to learn about M&O procedures and M&O had to learn about the Highway Analysis System transportation database and data collection procedures.

2. Deficiencies and inconsistencies between the legacy databases, included outdated M&O Station Files, inconsistent accounting system codes between legacy databases, and incompatible bridge information in other systems with PONTIS bridge manage-ment system.

3. Planning and M&O started out with different perceptions on the type of system to be developed. M&O wanted a stand-alone MMS system with no real-time data linkage to other systems while Planning wanted to avoid costly (time and funding) changes to HAS, the Department's legacy database.

4. Planning and M&O had considerable discussions on the data collection standards, especially the desired data fields and what could realistically be done within person-nel, time, and funding limitations. GIS mapping helped focus on two areas:

   – Location Accuracy – required versus what is achievable; and
   – Safe and reliable measurements of asset attributes.

Future Plans

ADOT&PF hopes to leverage the MMS data collection, archive, and access to benefit other Statewide Planning work and the data interests of other agencies, including but not limited to:

- Alaska Traveler Information System (CARS/511);
- Vehicle Crash Reporting;
- Highway Inventory;
- Legislative Support;
- Federal Reporting such as HPMS;
- GIS Development;
- State Transportation Improvement Program (STIP); and
- Highway Safety Improvement Program (HSIP).

The agency will be looking for more guidance from FHWA, TRB, and AASHTO concerning Asset Management implementation. They also will draw from data integration efforts and experiences of other states particularly the success stories. Finally, they intend to participate in workshops and discussions on this topic.

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Arizona DOT Information Data Warehouse

History/Background

ADOT has long realized that an integrated information system is critical for its future infrastructure planning and management practices. Such a system would provide a one-stop shop for disseminating accurate enterprise information to all internal and external customers. ADOT defines enterprise data as "data viewed at the department-wide level." At this time, data required to support a decision may be collected and maintained but it is not always readily available to decision-makers.

In 2000, ADOT opted to use the modified approach in response to the Governmental Accounting Standards Board (GASB) Statement 34 requirement that state and local agencies report the value of their transportation infrastructure in their financial statements. At the same time, ADOT was evaluating opportunities to implement Transportation Asset Management concepts and techniques. ADOT has completed an implementation plan for a Transportation Infrastructure Asset Management System (TIAMS). The implementation plan establishes a formal link between ADOT's Information Technology efforts and its Asset Management initiatives by recognizing that improved data quality and management are required for a successful TIAMS.

GASB 34 and the TIAMS plan provided the catalyst for developing the ADOT Information Data Warehouse (AIDW). Development of the data warehouse began in 2001 and is expected to be complete in 2006.

Integrated Data Considerations

Although the AIDW was designed initially to support GASB 34 reporting, it will eventually act as an Executive Information System (EIS) and a decision support tool for ADOT, its local planning partners, and the legislature in supporting broader asset planning and management functions. The sole purpose of the AIDW is to "deliver the right information, in the right amount, to the right people at the right time." For example, when fully implemented, it is expected that agency staff will use the AIDW to answer the following types of questions:

- How much money was spent in a county for pavement preservation in the past two years?
- What was the impact on congestion of opening a major loop segment?
- What was the total cost of widening a corridor?

- What is the total cost of scope changes made during implementation of the capital program?
- How much money has been spent on studies and pre-design work for projects that were not implemented?

ADOT collects a wide variety of data through its management and operations systems and databases. It is anticipated that the AIDW will integrate five types of data – asset, maintenance, finance, project, and traffic. The systems that store these data have been built over the years on different platforms and with little integration. Therefore, many data integration challenges exist, including:

- The same data is collected by different units or copied from one system to another, often manually, resulting in inaccuracies and redundancies;
- Many staff add to databases, but keep them in their own Access databases or Excel spreadsheets;
- Lack of defined data ownership and accountability for data quality; and
- Major data gaps and disconnects.

In July 2000, ADOT adopted its Transportation Planning Division's Arizona Transportation Information System (ATIS) as the standard centerline mapping system. ATIS uses a spatially referenced data layer containing information on 80 percent of all public roads in Arizona. ATIS also uses a Location Referencing System that enables any data with a latitude and longitude or route and milepost component to be easily mapped. However, slow progress has been made to ensure location is validated for every record in each database. ATIS is the proposed reference system for the AIDW.

Integrated Data Architecture

The AIDW will be an online analytical processing (OLAP)[1] system and database that will serve as a read-only repository of information. The system will use a WINDOWS 2000 Server and SQL Server 2000. Microsoft's Analysis Services and Data Transformation Services (both of which are components of SQL Server 2000) will provide OLAP capabilities. Users will have web access to the AIDW, initially through ADOT's intranet. ESRI's ArcIMS and ArcSDE (Spatial Database Engine) will provide an "enterprise-level" GIS solution for queries and results without requiring uses to store large shape files locally.

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[1] An OLAP provides "fast analysis of shared multidimensional information." It enables users to perform ad hoc queries of large data sets (known as data cubes) and analyze the results. Users execute queries of the data using Multi-Dimensional eXpression (MDX) instead of the SQL language normally used for relational databases.

ADOT also is developing a series of business intelligence tools to enable users with little or no technical training to access more easily the data warehouse. Users will query data using an online interface or GIS with point-and-click, drag-and-drop query capabilities. Users also will be able to retrieve data from summary to details, and drill across to get information on projects, traffic, accidents, features, maintenance history, etc., at any given milepost.

Lessons Learned

ADOT believes that the AIDW concept/architecture represents the fastest and cheapest way to have quality, integrated data, as opposed to re-writing all management and operations systems. The challenges faced during this effort are one-third technical, one-third cultural, and one-third business processes. Simply pulling data from many sources into one repository does not work – quality issues have to be addressed and data disconnects have to be fixed at the source. To address these root problems, ADOT continues to implement the following principles.

- **Accountability.** Data quality is much more important than quantity (however in order to make any type of decision a sufficient quantity of data must be available).

- **Information Resource Management (IRM).** Enterprise data needs to be identified and managed in the same fashion as human resources and capital assets. Ownership must be assigned and standards must be set. Collection and processing rules must be documented and available. Resources must be allocated. The AIDW is a tool within IRM. IRM aligns IT strategy to business strategy through data and information tools.

- **Business Process Improvement (BPI).** Data disconnects are symptoms of business processes that are less than optimized. Streamlined business processes uplift an organization's performance and result in good information flow.

- **Cultural transformation.** Change management is required from project orientation to process orientation; from reliance on precedence to reliance on facts and information. This has been one of ADOT's toughest challenges.

- **Organizational alignment.** ADOT has been improving its business operations through organization changes. In some cases the changes are not efficient or do not add value. ADOT would like to review its organizational structure and realign it as required. Organization goals would be translated to process measurements and to individual performance measurements.

- **Balance between top-down commitment and bottom-up desire.** A strong mandate for a comprehensive data integration initiative from above is unlikely to happen. Bottom up desire is usually strong, but can be uncoordinated, particularly across Divisions, and alone cannot provide the impetus for moving forward. A critical success factor is a carefully blended mix.

The following lessons can be learned from ADOT's work on the AIDW:

- The traditional data warehouse OLAP model is multi-dimensional, as in snowflake or star schema. For example, there are dimensions (calendar, geography, project, asset, organization, etc.) and facts (or measures). The dimensions are what users slice and dice to answer business questions. Facts are numbers (budget, costs, miles, etc.) that are aggregated by dimensions and their hierarchies (e.g., project monies spent in a city, county, district, or statewide). This model works well in a sales analysis scenario in private industries. However, it does not work well in a DOT core business, where most data is descriptive (bridge name and type, project description and timeline, etc.) rather than quantitative or additive. ADOT uses a mixture of relational (ROLAP) and multi-dimensional (MOLAP) models.

- Data warehousing and GIS remain two separate worlds in the Information Technology field. When staff with different backgrounds talk about data warehousing, they mean different things. Data warehousing is database-intensive. GIS traditionally is flat-file-based and represents one dimension (geography) in answering business questions. It is only recently that the GIS environment has moved towards the spatial database model. It will take some time before these two areas converge.

- Data ownership and accountability play a key role in ADOT's data integration efforts. To this end, AIDW staff have worked to help operational units (planners and engineers) understand that they "own" the data they collect and are responsible for its integrity. IT staff are merely "custodians" of the data, and the data warehouse merely a tool with which to access the data.

- ADOT's success to date is largely due to its focus on delivery. AIDW staff strives to deliver a data source every three to four months, so they are not seen as only talking about what is possible. It is important to augment a vision and architecture with practical progress.

- When beginning a data integration initiative, there may be a strong urge to build the meta-data and data dictionary layer first. ADOT has learned that this does not bring practical value quickly and may cause people to lose interest. Instead, the thousands of data elements that make up enterprise data will still be identified, documented, and assigned ownership, but in parallel to delivering the analytic tool. Meta data, though important, is a means and not an end.

- Another critical success factor is the ability to match the tools to the users. ADOT's vision is to use business intelligence tools already available in the private sector. However, these tools should not be implemented until they match ADOT's organizational maturity. For example, until the culture is transformed to information-reliant, until the skill set is upgraded to ask and answer business questions and what-ifs, business intelligence and data mining tools are extraneous. ADOT's approach has been to ensure that the proper platform is available to plug-and-play new tools, as the organization becomes ready to use them. If an agency implements tools prematurely and turns them over to planners and engineers to use, the success of the overall data warehouse initiative may become incorrectly tied to the success of individual tools.

- It is important to have a solid IT vision and architecture, because technology becomes rapidly obsolete, and it is burdensome and inefficient to rewrite code every few years. This vision needs to accommodate "plug-and-play" tools so that an agency does not have to reinvent the wheel. However, it is equally important to be flexible when pulling in data sources, because priorities often shift. Anticipating the next "crisis" and being ready with the data wins every time.

- One key data warehouse principle is not to alter the original data from the source. Data "transformation" is limited to little more than geo-coding – cleansing the geographical information (route, milepost, and offset). Much of the data is not validated at the source end up in "unknown" buckets. ADOT has found that it is critical for data ownership to be clear, and processes to be built to feedback anomalies to the data owners. It also is critical to create buy in from data owners so that they understand the importance of changing their systems to validate data at entry.

Future Plans

Since 2001, the following data sources have been integrated into the AIDW:

- Photo log available at the District Offices;
- Pavement and bridge data;
- Project expenditures;
- As-built engineering drawings, in PDF format;
- Priority programming and HPMS data; and
- Safety/accident data.

Additional data will be prioritized and brought in one at a time. Currently ADOT is working on a GIS user interface and including construction data into the AIDW.

ADOT also is completing a six-month business process improvement project. The objective of this project is to map the "as-is" core ADOT business processes from Planning to Maintenance. The nine macro-level processes include: Scoping, Priority Programming, Five-Year Plan Update, Design and Pre-Construction, Construction, Maintenance, Program Budgeting, Project Accounting, and Contract Accounting. Each process is complete with a process description, a linear flowchart, a cross-functional chart, and an information use matrix. The matrix, which maps information use across business processes, will serve as the basis for future enterprise data work.

The BPI project will make recommendations to ADOT senior management on how to prioritize and improve business processes holistically. The recommendations also will address such issues as organizational alignment and process-oriented performance measures. This project is envisioned to be the launch pad for both a comprehensive BPI effort and Information Resource Management (IRM). Both initiatives are gaining traction in support from both executive management and operational management.

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California DOT Intermodal Transportation Management System

History/Background

The vision for data integration at the California Department of Transportation (Caltrans) consists of collecting and managing the "right" data; applying tools that enable customers to view, analyze, and present information; enabling data and tools to work seamlessly; requiring minimal special requirements (e.g., training, hardware, etc.) for using the systems; and providing customized views and queries that support decision-makers and policy-makers. Caltrans has developed incremental plans for implementing this vision, beginning with well-defined, non-controversial data needs.

Data integration activities at Caltrans that have been identified in literature include:

- Implementation of a freeway Performance Measurement System (PeMS), a consolidated database for data collected by loop detectors from across the State;
- Development of a statewide GIS;
- Implementation of an integrated bridge management database; and
- Updates to the Intermodal Transportation Management Systems (ITMS).

This review focuses on Caltrans' ITMS, a stand-alone statewide sketch-planning tool that enables users to analyze multimodal investment options at the corridor, regional, or statewide level. This tool was first released in 1996 in response to the Intermodal Surface Transportation Efficiency Act (ISTEA) requirements. Since that time, it has undergone a series of updates, with Version 4 scheduled for release in 2004. The update effort consisted of defining stakeholder needs, identifying multimodal performance measures, confining the transportation network to a manageable and relevant size, developing an analytical framework and user interface, collecting supporting data, integrating components into the final system, and training staff to use the system.

A project staff of four within the Division of Transportation Planning is responsible for ITMS. In addition, a 40-person ITMS user group was created to support the effort. Members of this group represent Federal, state, local, and private organizations.

Integrated Data Considerations

Roughly 600 users (from Caltrans and external organizations) use ITMS to evaluate transportation investment alternatives. Specifically, they rely on ITMS to identify deficiencies, analyze system demand and capacity, develop strategies for addressing the deficiencies, evaluate their expected impact on system performance, and generate reports based on the results.

ITMS includes spatial and attribute data on highways, buses, passenger rail, air routes, pipelines, shipping lanes, freight rail, cruise terminals, intermodal freight facilities, ports, tanker terminals, transit, and airports. The system also includes passenger and freight travel data, a passenger mode-shift model, census data, and a wide range of performance measures.

ITMS represents a very broad data integration effort – integration of data from over 400 data sets that are maintained by over 250 public and commercial organizations into a single, stand-alone decision support system. Example data sources include Caltrans' Traffic Accident Surveillance and Analysis System, the commercially available TRANSEARCH database, and regional travel demand models. Example data custodians include Caltrans, the Federal Highway Administration, the Federal Aviation Commission, the Environmental Protection Agency, the Army Corps of Engineers, and metropolitan planning agencies.

ITMS source data represents lines (e.g., highways), points (e.g., airports), and polygons (e.g., state boundaries). The data is translated into a consistent GIS projection using spatial look-up tables based on Caltrans' ArcView database. Users also are provided instructions on translating the data to other referencing systems.

Integrated Data Architecture

The ITMS uses data that is stored in a series of stand-alone flat files. Caltrans updates this static data set every few years. The update process begins by identifying and collecting relevant data from the sources described above. This data is then integrated by "forcing" it into a time series of flat files. This process requires significant assumptions because of the wide range of types and quality of data being integrated. The conversion process and all assumptions are thoroughly documented in the *ITMS User's Guide*[4]. Once the integration process is complete, the flat files and user interface are packaged onto CDs and distributed to the users. ITMS is compatible with any workstation that has ESRI ArcView 3.x installed.

This update process is labor intensive and takes a few years to complete. The current version (Version 3) is based on data from 1996. Version 4 will be based on 2000 data and will provide projections through 2030.

Because ITMS users are working with a static snapshot of data, the system provides absolute relative results rather than absolute correct results. For example, users can rank investment alternatives relative to one another based on their expected impact on air quality or mobility. However, determining the most recent projected values of these measures for the highest ranked project would require a user to consult the actual travel demand model from the region in question.

Lessons Learned

The ITMS project team has relied extensively on a team of consultants to provide the staffing resources and technical expertise required for the ITMS program. Without these outside resources, ITMS work would not be possible.

ITMS staff have investigated the use of a relational database instead of flat files and the development of an online application. So far, they have concluded that a database may inhibit the delivery of the system. (Currently the system can be installed on any workstation with ArcView 3.x.) They also have found that a web application may limit the system's functionality and, therefore, may not be worth the cost of development.

Significant involvement of the end users, canned analysis and reporting routines, a flexible user interface, and a formal training program have fostered widespread acceptance for and use of ITMS. Over 300 users have completed a weeklong ITMS training course. Use also has increased recently because ITMS is the only system at Caltrans capable of multimodal analysis.

Finally, developing and updating ITMS represents a long and detailed process that involves working with over 200 organizations. Patience and diligence of the project team continue to be the two most critical ingredients for success.

Future Plans

The decision-making environment at Caltrans has recently become more rigorous in response to increased competition for limited resources. As a result, the value of enterprise data and the need for quality data continue to increase. For example, Caltrans performance measure initiatives have increased interest in ITMS. The system currently predicts 15 performance measures in the areas of mobility, finance, air quality, economic development, and safety. At the time these measures were initially developed, performance-based approaches had not yet taken hold throughout the agency. The project team developed the system by applying currently available data to state-of-the-art performance measurement guidance. As Caltrans institutionalizes new performance measures, the ITMS team will work with existing data to develop approaches that support them. However, this process is complicated because ITMS capabilities are constrained by Caltrans' existing data resources. For example, although there is great interest in freight analysis, no complete freight data set is available. In response, Caltrans has asked that the Federal authorization guidelines include provisions for the collection of freight data at the zip code level (at a minimum). ITMS is unable to meet the agency's full freight needs until progress has been made in this area.

Caltrans also would like to enhance ITMS' analytical capabilities. Currently the system analyzes highways (based on congestion) and railroads (based on geometry and speed). The system includes placeholders for analyzing other modes (e.g., airports and ports), but analytical approaches have not yet been developed in these areas.

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Colorado DOT Integrated Asset Management Planning and Programming

■ History/Background

The Colorado Department of Transportation (CDOT), in consultation with the Colorado Transportation Commission, has taken a number of steps toward improving their Asset Management program. A major development was the establishment of its Investment Category structure, which organizes program investments within a policy-oriented framework and identifies explicit measures of performance. Recent efforts that complement the Investment Category approach include updates of the statewide planning process, the program prioritization process, the establishment of maintenance program, levels of service, institution of the use of customer surveys, and updates of relevant information technology applications. CDOT also has developed an Asset Management Plan that recommends specific actions to build upon and expand these accomplishments. Highlights of the plan include:

- Completion of all elements of the Investment Category structure;
- Incorporation of Asset Management principles in CDOT's planning and programming processes, building on a tiered structuring of CDOT assets;
- Integration of Asset Management information on a GIS platform, and renewal of Information Technology strategic planning to support Asset Management department-wide; and
- Strengthening of program delivery mechanisms and measures.

CDOT recently established an Asset Management Task Force to oversee the implementation of its Asset Management Plan. The Task Force is headed by the Deputy Director of CDOT and includes 10 representatives from across the CDOT.

The objectives of this Task Force include:

- To provide high-level leadership and demonstrate buy-in of the program by Departmental executives and managers to CDOT staff and outside stakeholders;
- To translate recommendations into actions quickly, maintain a long-term perspective on objectives and tasks, periodically assess planned versus actual accomplishments, and perform mid-course adjustments when needed;

- To coordinate actions across Departmental organizational units, and guide development and implementation of integrated practices where needed (e.g., data collection and processing, evolution of GIS capabilities);
- To view the Department's activities and decision processes from a strategic as well as tactical perspective in applying Asset Management principles; and
- To provide a credible and effective organizational basis for communication of plans and accomplishments to the Transportation Commission and to be able to implement the Commission's recommendations regarding Asset Management efficiently and effectively.

In performing its responsibilities, the Task Force is able to address the Transportation Commission's concerns that Asset Management not become simply another program, and the Task Force another layer of bureaucracy. In its consideration of a wide range of business process and IT issues, the Task Force is working to maintain the premise that Asset Management is "a way of doing business."

CDOT has identified several incentives to implement the activities in its Asset Management Plan. The following examples of benefits are organized around the four key areas of the plan.

- Policy and Institutional Benefits:
  - More comprehensive understanding of transportation impacts of CDOT's total program; and
  - Enhanced systemwide decisions – wider alternatives and potential cost savings for solutions to state transportation problems.
- Planning and programming benefits:
  - Rational basis for standards, levels of service, and interpretation of performance throughout system; and
  - Stronger basis for program delivery and accountability.
- Program delivery benefits:
  - Ability to maintain program consistency and ensure full value received for funds expended; and
  - Maintenance of stable network condition at least life-cycle cost.
- Information and analysis benefits:
  - Better, smarter use of existing system capabilities; and
  - Security of critical support and effective planning for information needs now and in the future.

CDOT's Asset Management Plan recommended reconstituting the existing Information Technology Resource Team (ITRT) to provide high-level IT expertise to the Asset Management Task Force and to represent CDOT "customers" of IT applications and information. The ITRT was then charged with developing an Information Technology Plan that specifically addresses IT support of Asset Management. A key objective of this plan was to propose steps for renewal or redevelopment of CDOT's legacy Asset Management systems, and integration of data from these systems using a geographic information system (GIS) platform.

Integrated Data Considerations

There are three components to CDOT's data integration approach: metadata, data model and use of GIS as a centerpiece.

Metadata

The process of developing a data dictionary has allowed CDOT to catalogue the data they have. This assessment also has allowed for the identification of duplicate data.

Data Model

The data in several of CDOT's management systems are currently being migrated to Oracle by the Information Technology Department within CDOT. The first management systems to be converted to Oracle within the next year or two will be pavement, maintenance, and bridge. The next ones, within the next three to four years, will be financial, roadway, and traffic data management systems. Once all data is in place, generic tradeoff analysis will be possible.

CDOT plans to use Brio software from Brio Software, Inc. to generate standard reports. The advantage of this tool is the ability to generate ad hoc queries and reports from the management system data in Oracle without using other software. Brio provides web-based reporting and analysis software.

Use of GIS as Centerpiece

CDOT has had a GIS operating within its Division of Transportation Development for several years. This system is widely accessible to CDOT staff and uses ESRI software. The GIS displays information on highway and aviation transportation assets, and is updated through links to the data warehouse and databases associated with individual management systems. GIS is now applied to a number of objectives, including analyses of environmental impacts, project scope studies, identification of maintenance, bridge needs, and planning studies.

Efforts are underway to broaden the usefulness of GIS to a wider audience within CDOT. This effort entails promoting GIS information as an asset, strengthening its analytic capabilities to be of use to a number of groups, and to provide information in a way that assists high-level decisions. Greater use of GIS on the Internet and continued development of web-based tools, user ability to obtain customized maps and ad hoc reports, data mining capabilities, and the combination of GIS tools with complementary analytical capabilities of specialized management systems also point to growing uses of GIS at CDOT in the future.

A 1:24,000 scale basemap has been established and all transportation data sets will eventually be available through an interface with the map. Data will be referenced linearly by route/reference. Currently, bridge locations, pavement data, traffic counts, and other highway data are available through access to the basemap. The GIS section is also in the process on converting shape files into Oracle Spatial Data Engine (SDE) files.

GIS data collection standards have been developed so any GIS data collected on eight pilot corridors will be consistent and easily integrated with other corridor data. These types of data include aerial photography, environmental data, remote sensing, and surveying.

Integrated Data Architecture

CDOT has been developing a comprehensive departmental data warehouse for more than 10 years. The design of this data warehouse calls for information on virtually all of the Department's internal and external business processes:

- Colorado general information – e.g., county information, historical information;
- CDOT organizational information;
- Human resources – departmental staffing levels, employee classification, employee listing, individual employee records, histories, (compensation, leave, performance, training, medical, etc.), and workman's compensation information;
- Financial – financial accounting (revenues, expenditures, fund transfers, grants, damage claims), budget, payroll, procurement, indirect cost allocation, materials, supplies inventories/stores, and fixed assets (non-highway buildings, furniture and equipment);
- Projects – construction project pipeline; project data, design data; right-of-way inventory; project agreements; project contract data; project histories, engineer's estimates, bid tabulations, and project materials test data;
- Equipment – departmental vehicle inventory, usage, maintenance, fuel; and
- Transportation infrastructure:
  - Highway inventory – HPMS data (100 percent sample), segment definition and location, segment classification, structural and operational characteristics, traffic volumes (AADT), locational information, and railroad crossings;
  - Safety – location, number, type/severity, time of crashes; crash circumstances and factors;

- Transportation infrastructure management – pavements, bridges and other structures (including border structure information), signs, access control points, intersections, and inspection histories;
- Highway maintenance – roadway surfaces and shoulders, roadsides, drainage, structures, traffic features, tunnels, rest areas, maintenance yards and equipment; maintenance labor, equipment, and materials costs;
- Environmental impacts – sites of potential impacts regarding hazardous materials, ecological impacts, cultural impacts, noise pollution, project review information; and
- Customer event tracking – complaints and resolutions.

CDOT currently uses several management systems that are important to Asset Management. Broadened application of these systems, additional improvements in systems features and capabilities, and integration of systems logic or data will advance CDOT's Asset Management practice. Following is a summary of the major systems capabilities and their status regarding Asset Management.

Pontis Bridge Management System

CDOT now uses Pontis as a database repository for inventory and condition information on state-owned "on-system" and local "off-system" bridges. Part of this information is shared with maintenance management for performance-based budgeting, as described below. However, CDOT to date has not made significant use of Pontis' analytic capabilities for scenario testing in relation to program development.

Pavement Management

CDOT's Pavement Management System (PMS) assists the agency in tracking current pavement condition and estimating future needs to maintain the pavement network according to specified performance goals.

Maintenance Management

CDOT's Maintenance Management System (MMS) tracks expenditures and accomplishments by activity as organized in nine maintenance program areas. This system has been supplemented with a performance-based budgeting tool that incorporates explicit levels of service related to the condition of highway maintainable items and to levels of activity performance or responsiveness.

Budget and Financial Management

CDOT's financial management systems provide information on the funding and expenditure dimensions of Asset Management (e.g., the "true" costs of Asset Management activities that include indirect cost components and other adjustments that are not accounted for in infrastructure management systems).

These systems will be linked through the integrated data structure described above.

Lessons Learned

One of the major challenges has been overcoming the mentality that "we have always done it this way." Many legacy system owners were not willing to participate in activities that resulted in combining data sources. Over time, the turnover and staffing changes at CDOT have resulted in leadership that is more visionary and a culture, which is more open to making changes. In addition, the agency's emphasis on a performance-based planning approach made it clear that the use of data to drive decisions is important.

Future Plans

The Asset Management Task Force meets monthly and is currently waiting for the Transportation Commission to complete the evaluation of the state's resource allocation process. Once that process is complete, the Task Force will reconvene to plan the implementation of the Commission's recommendations.

The tradeoff analysis using the Investment Categories referred to earlier will be developed in-house by CDOT.

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Information for this detailed review was compiled with the assistance of the following CDOT employees:

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Delaware DOT Integrated Transportation Management System

History/Background

The Delaware Department of Transportation (DelDOT) has undertaken major initiatives in the Intelligent Transportation Systems (ITS)/operations arena that make use of state-of-the-art information systems technology such as GIS and emphasize open, enterprise-level software architecture. The DelTrac program is one such initiative. The DelTrac Integrated Transportation Management System (ITMS), initiated in 1999, and the initial components of the system are now in place. DelTrac is an ambitious effort to provide real-time multi-modal transportation management capabilities, encompassing operations, monitoring, and traveler information elements.

DelDOT also has put GIS capabilities in place to integrate traffic accident data, bridge information, and high-level capital project information. It intends to implement a GIS environment that allows for integration of a variety of other enterprise data. Enterprise data items have not been finalized, but may include pavement management, video pipe inspection data, storm water facility management data, maintenance management data, truck permit data, equipment data, and vendor data. The Bentley Systems, Inc. geographic referencing engine has been selected to support this effort.

Integrated Data Considerations

The DelTrac ITMS is designed to support multimodal transportation systems. It stores information from legacy systems and from new system components, including real-time traffic data. Key features of the system include:

- Centralized, integrated control of the 1,000 state-owned traffic signals (and by agreement, those in the cities of Wilmington and potentially Dover as well);
- Real-time video traffic monitoring, with information supplied on the web, at information kiosks, and by other means;
- Electronic detection systems – providing information on system condition, use, and performance;
- Electronic toll collection;
- Real-time weather and road surface condition information;

- Control of changeable message signs that will be used to implement a variable speed limit system (in which speed limits are modified in response to incidents, weather conditions or air pollution levels); and
- Interfaces with police and fire department computer aided dispatch systems.

The goal of DelTrac ITMS has been to construct a "standard transportation workstation" that allows users with appropriate authorization to perform planning and real-time operations functions using a single database.

Integrated Data Architecture

DelDOT uses Oracle and Oracle Spatial as the database standard, WebLogic as the application server, and Java or XML for the development of the web client application. This architecture is in place for the ITMS and for the permitting system.

The agency also has purchased a location-based service (LBS) application from TransDecisions, Inc. (now Bentley Systems, Inc.). The LBS translates across different location methods, including coordinate-based, linear referencing-based (route-milepost) and address-based. It was developed in Java and was designed to be a generic component that can be utilized by a variety of applications.

Lessons Learned

DelDOT's ITS unit understands that traffic management technologies can be a viable alternative to highway capacity expansion. ITS technologies can increase the capacity of an existing roadway and decrease congestion. The ITS units are working to integrate traffic management capabilities into other department functions (e.g., policy development, planning, programming, design, etc.). It is focusing on urban corridors where dense development prohibit expansion work, and is working with engineers to include ITS hardware in the design of new facilities in order to extend their functional life. DelDOT also is working to increase general awareness of DelTrac both internally and externally. To this end, it publishes ITS brochures, meets with representatives from departments across the agency to discuss the application of DelTrac to their business functions, and promotes tours of its newly completed traffic management center (TMC). The main objective of these efforts is to "market" transportation management rather than to explain the technical details of DelDOT's ITS technologies.

As ITS technologies evolve, DelDOT is adhering closely to Federal guidance and standards such as the Traffic Management Data Dictionary (TMDD), developed jointly by the Institute of Transportation Engineers (ITE) and the American Association of State Highway and Transportation Officials (AASHTO). The agency feels that following these standards now will result in an open and flexible architecture that permits incorporation of future technologies.

One of the key lessons learned from the DelTrac experience has been the need for ongoing staff training to support the implementation and operation of the program. Accordingly, DelDOT, in partnership with the University of Delaware, implemented a research laboratory and training facility focused on DelTrac functions. DelTrac staff also learned the importance of considering long-term system operation and maintenance costs during development and implementation phases.

Future Plans

DelDOT's Office of Information Technology is developing an Integrated Enterprise Environment. This effort will define a strategy for an exchange engine that will enable widespread data integration within the agency. It includes an audit of existing agency systems, development of an enterprise data model (EDM), evaluation of data integration strategies (e.g., development of an operational data store (ODS), and identification of options for accessing the data. DelDOT is approaching this initiative in the context of an agencywide integration strategy rather than an application-by-application effort.

DelDOT recently issued a request for proposals for integrating its legacy ITS data into a single database. This ITS database will be the basis for future traffic management systems and will be a source of data for the ODS described above.

The DelTrac effort will be expanded to include a number of additional components. These components will include a priority treatment system for transit, improved weather and road surface monitoring, expanded electronic toll collection, traveler information, electronic payments using smart cards for use across multiple modes (parking, transit, rail), and passenger information displays at bus and rail stops linked to automated transit vehicle location (AVL) information. DelDOT is constructing a 250 to 300-mile statewide fiber optic system to support DelTrac's current and future communication components. The department is installing a new statewide wireless communication system to support the Variable Speed Limit (VSL) system and other DelTrac components. DelDOT also is working to integrate DelTrac's customer event tracking capabilities with those of Maximo, the department's maintenance management system.

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Florida DOT Geo-Referenced Information Portal

History/Background

Several data integration efforts are underway at the Florida Department of Transportation (FDOT). These include the Turnpike Enterprise Asset Management System (TEAMS), the Transportation Automated Information Management System (TAIMS), the Geo-Referenced Information Portal (GRIP), and the Civil Engineering Data Integration System (CEDIS). This review focuses on GRIP, which is FDOT's GIS-based enterprise data integration system.

In the past, transportation data within FDOT was contained in a variety of disparate databases including Oracle, mainframe flat files, and FoxPro platforms. There were redundant copies of data throughout the functional areas and districts. As a result, data integrity was serious concern. There were numerous islands of fat client applications to access and analyze data. Functional area barriers existed where data flowed vertically, providing little opportunity for integrated decision-making across management systems.

In 1999, the following requirements for an enterprise database system were developed:

- Provide accurate, integrated data;
- Handle numerous proprietary formats and data types;
- Leverage existing technologies and infrastructures; consistency in data reporting; and
- Provide a user-friendly interface with access to the enterprise data.

The goal of the GRIP project was to develop a geo-referenced information system capable of integrating diverse locational data from a variety of data sources. Objectives included managing data centrally, encouraging data sharing, increasing confidence in data quality, enhancing decision-making, eliminating redundant collection and storage of information, and providing up-to-date information.

The newly created office of Specialized Technology within FDOT assumed the responsibility for developing this enterprise system. Consultants were hired to supplement FDOT staff, and the project began in late 1999. Extensive stakeholder working sessions were conducted to ensure that user needs would be met. An existing Transportation Data Steering Committee comprised of managers from all offices in the Central FDOT Office served as a sounding board for ideas related to concept, data to be included, and desirable applications within the GRIP. Early phases of the application were rolled out as a pilot and further enhancements are underway.

Integrated Data Considerations

Business processes for the development of GRIP were established at the beginning of the project. It was made clear that GRIP administrators would not own data. FDOT data owners were identified and responsibilities related to data update and accuracy were clearly established. Data owners were required to:

- Make the data available on a server;
- Have a data dictionary;
- Have metadata;
- Have back up copies;
- Have a defined process for collection and quality control; and
- Provide for future maintenance of the data sets.

The first iteration of GRIP includes the following data:

- Project development and work program (including planning, environmental, design, right-of-way, and construction);
- Roadway Characteristics Inventory System;
- Airports;
- PONTIS bridge information;
- Pavement condition; and
- Background imagery (digital orthophoto quarter quads).

GRIP interactively and visually integrates multiple datasets, provides the user with a set of navigational tools, automates handling of version control, has the ability to view CADD files and imagery files; and provides linkage to the metadata.

One of the most important aspects of GRIP is that it is not intended to eliminate or replace existing applications. Rather it serves to integrate and disseminate data while leveraging existing technology and infrastructure.

One of the critical decisions in the development of the GRIP was the agreement on a base map. The Planning Office's 1:24,000 GIS base map was selected as the official base map. It is maintained by the Planning office and is an important tool for linking the data through a common referencing system.

The GRIP supports multiple views allowing access to different views with user-defined functionalities. Example views are Asset Management, emergency management, program development, and public transportation. Regardless of the view, the users are looking at the same enterprise databases. Example functionalities include the ability to add specialized data sets, customize available data, specify query retrievals, and perform spatial analysis (buffers, etc.). Update and manipulation functions are available to data owners only.

The GRIP project is made up of the following phases:

- **Phase 1 –** Create an Enterprise Information System vision, establish functional and data requirements, design program structure, and develop an enterprise base map;
- **Phase 2 –** Develop a working system with specific, defined functionality;
- **Phase 3 –** Integrate priority data areas; integrate transportation model data in GIS, database design, application design and refinement, and technical architecture;
- **Phase 4 –** Make the Enterprise Information System accessible to all users via Intranet and browser GUI, port all data into Oracle data repository; and
- **Phase 5 –** Develop additional applications for different users sharing the same database.

The Enterprise Information System will support Asset Management, emergency management, program development, public transportation, and safety management.

Integrated Data Architecture

GRIP is an application that allows centralized management and supports an unlimited number of users. It provides users an interface for access to the centralized database (including legacy systems) via FDOT's intranet. It consists of an integrated multi-layered GIS spatial database as well as attribute and image servers residing in each of the FDOT districts. Personal computers connect to the server via the intranet through Local Area Network (LAN), Wide Area Network (WAN), Remote Access Server (RAS), or Virtual Private Network (VPN) connections. Users access GRIP through Internet Explorer. The application is designed to meet the needs of heavy as well as casual users. Oracle 8.17 is used with the full spatial capabilities to maintain the GIS data. In the initial version of GRIP, Formida Fire, an advanced application which links complex data (including spatial, image, video, audio, and time series), was used to serve it to the web.

Lessons Learned

A variety of institutional issues were identified during the development of GRIP including obtaining buy-in related to the benefits of such a system. These issues were overcome with clearly established guidelines and full executive support. A technical challenge for the project is FDOT's adoption of distributed database architecture instead of a centralized database to preserve bandwidth.

Some of the barriers and constraints for gaining support for the project included:

- Difficulty quantifying benefit/cost;
- Resistance to change;
- Gaining user support – both initially and as the development progressed;
- Promoting needs to managers;
- Securing budget issues from legislature; and
- Maintaining focus.

Some of the benefits being realized by the application of the GRIP include:

- Ability to support decision-making;
- Cost savings in data access;
- Tool for improving quality control;
- Reduction of application and data islands;
- Improved data collection/utility; and
- More efficient use of data.

Lessons learned include:

- Develop new processes to provide a coordinated approach to collection and use of data;
- Obtain a good understanding of data needs, including the level of required accuracy;
- Agree on the best method for obtaining data;
- Make all data available to all offices;
- Determine actual benefits and cost savings;
- Maintain executive buy-in;
- Secure continual support;
- Educate and train users; and
- Ensure careful planning, cooperation, and coordination with aggressive implementation.

Asset Management is defined broadly by FDOT as a holistic approach used for decision-making, investment analysis and management of transportation assets. It is the entire process from programming and planning to preservation of the transportation system and is characterized by a solid policy framework, measurable objectives, and continuous performance monitoring resulting in sound investment decisions with a customer focus. The Asset Management concepts of informed decision-making, performance-based management systems, strong relationships between condition and performance, and an emphasis on tradeoff and investment analysis are integral components of daily activities at the Department. The concepts are part of the culture and are strongly supported by upper management. They transcend planning and financial management to maintenance, bridge, and pavement offices. No single office is responsible for Asset Management; rather, Asset Management permeates the department with the planning office responsible for evaluating and reporting the results against goals and objectives. GRIP and the associated business processes for data integration within the department support Asset Management by providing a centralized tool that is widely accepted and effectively used for planning and programming decisions.

Future Plans

GRIP has helped FDOT establish a centralized system to permit integration of applications across functional areas. The department plans to continue with the next phases of the GRIP, which include updating the tools using GIS products to be consistent with FDOT standards.

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Acknowledgment

Information for this detailed review was compiled with the assistance of April Blackburn, Office of Specialized Technology, Florida DOT.

Florida DOT Turnpike Enterprise Asset Management System

History/Background

The Turnpike Enterprise is the largest toll road system in Florida and the fourth largest in the United States. The Florida legislature recently designated the Turnpike as an enterprise within the Florida Department of Transportation (FDOT). The Turnpike is approximately 449 miles in length, serves over one million customers per day, and has a significant inventory of guardrails, signs, lighting, and buildings.

The Turnpike Enterprise Asset Management system (TEAMS) was developed to eliminate data duplication and provide a better means of collecting, storing, processing, analyzing, and reporting asset data for the Florida Turnpike Enterprise. The mission of TEAMS is "to assist all Turnpike personnel in efficiently and proactively managing the assets of the Turnpike by providing inventory, condition and forecasting information while ensuring the safety of customers and protection of investors." The impetus for the development of TEAMS was to provide a better method for tracking the condition of assets and for budgeting renewal and replacement needs. Work on TEAMS began in 2000 when investigation of "off-the-shelf" packages revealed that the Turnpike had special needs requiring the development of a unique tool. The goal of the project was to develop a user friendly, web-enabled, graphically driven desktop application that could be accessed by all Turnpike personnel. The development consisted of three steps:

- Identification of existing systems, processes, and preliminary hardware/software requirements;
- Development of a data collection process; and
- Implementation of a pilot program.

The tool itself consists of six modules: Facilities, Pavement, Roadway, Structures, Finance, and Video-log. TEAMS' interface allows the user to select and view data related to assets by geographic region.

It was determined that TEAMS would be released in a series of versions with each version adding new assets as data about them became available. The initial release of TEAMS version 1V01, which included a short list of assets, was in April 2002.

This release was followed by subsequent releases that included additional assets and functionality. Currently Release 8V05 is available and being used by Turnpike Enterprise personnel on a daily basis.

Integrated Data Considerations

Several planning and operating functions are supported by the integrated data in TEAMS. These include pavement, bridge, and facilities management as well as programming and budgeting. TEAMS will support the Turnpike Enterprise's Asset Management processes and allow the agency to manage repair and replacement costs for their assets.

The application integrates data from a diverse set of existing systems including spreadsheets, Microsoft Access databases, relational databases, state-mandated databases, and Federal databases.

While integrating so many diverse data sources was no small task, it was made somewhat easier because all FDOT legacy databases utilize a common linear referencing system (LRS). This is sometimes referred to as a section milepost location reference system. In FDOT's system, each highway is assigned an eight-character roadway identifier. The first two characters are the county number, the next three a section number, and the last three are reserved for a subsection number. When a highway extends to an adjoining county it is assigned a different identifier, thus the term "section." For example, Interstate 10, in the Florida panhandle, has 17 individual section numbers, one for each county it passes through. Subsection numbers are used for ramps or access roads.

Data are referenced to the section by milepost, a term that refers to the cumulative measurement in miles from the beginning of the section. In all FDOT legacy systems there are two fundamental types of data: linear and point. Linear data are referenced by two milepost values representing a milepost range along the section. Point data are referenced by a single milepost value. This data is positioned spatially with a GIS through a process called dynamic segmentation. This process requires a GIS data file that models the LRS – a cartographic representation of the road system coded with FDOT's roadway identifier. The process of dynamic segmentation spatially positions FDOT's data at the appropriate location along the roadway section.

The data collected specifically for TEAMS was compiled using either a form of global positioning system (GPS) or geo-referenced aerial photography (referred to as orthophotos). Both methods spatially reference the data by geographic coordinates. This data was either compiled with, or easily imported to, a GIS. In addition, to facilitate analysis and report generation of FDOT legacy data in a relational database environment, a GIS was used to automate assignment of the appropriate milepost value to data referenced with geographic coordinates, placing both data types in a common referencing system.

Integrated Data Architecture

TEAMS is a reporting tool, accessed using a standard web browser over the Enterprise's Turnpike intranet. The customized software components required for TEAMS were developed using an internationally recognized programming standard, Java 2 Enterprise Edition Standard (J2EE). These components constitute the graphic user interface and serve to integrate and coordinate the interoperability of the report generation tool (Crystal Reports Enterprise Edition), the GIS component (Intergraph GeoMedia Web Enterprise), and the relational database management systems (Oracle RDBMS).

TEAMS uses Oracle 9iAS as the web application server and Oracle 9i for its RDBMS. It is built on a data warehouse approach in combination with distributed databases. The development of TEAMS adheres to FDOT's software development standards.

TEAMS extracts and utilizes data from a variety of FDOT legacy systems. These systems include the Roadway Characteristics Inventory (RCI), the Financial Management System (FMS), and PONTIS bridge management system. RCI and FMS are mainframe systems. To facilitate use of these systems the Enterprise replicates data from these systems down to Oracle databases. TEAMS extracts the data from the Oracle version of these databases, including the PONTIS database. The required data is extracted and transformed from these systems on a nightly basis. While the department considered a live link to these databases, database design considerations as well as network traffic concerns limited the transactions to a nightly batch process. TEAMS also utilizes data from FDOT's Pavement Management System – a mainframe Statistical Analysis Software (SASS) application – and crash data from the department's Safety Office. This data is exported out of these systems into ASCII files, loaded into TEAMS, and updated by FDOT on an annual basis.

While currently not deployed, facilities data will be extracted from a third-party work order/inventory software package (DataStream 7i) in a fashion similar to RCI, FMS, and PONTIS. This software package is not yet in use by FDOT.

TEAMS also integrates multiple, stand-alone, personally managed database systems, i.e., condition assessment, roof maintenance, and facilities inventories. These systems vary in sophistication from hardcopy notebooks and spreadsheets to Microsoft Access databases. While these databases have historically met daily production requirements, their use requires a great deal of human interpretation. Many of these personal databases are not suited for import into a relational database. In some cases, automated transformation was impossible and the data had to be converted manually to a relational database format.

Lessons Learned

A variety of technical and institutional challenges were encountered in the project, including obtaining buy-in from the large number of stakeholders and potential users, overcoming territorial boundaries, incorporating all relevant databases, developing good relationships with other FDOT offices, and responding to data users' needs. Several focus group meetings, surveys, and interviews were conducted to determine user needs and the types of assets to include. The department demonstrated the benefits of Asset Management in general and TEAMS in particular to potential users to obtain support. Often times, reluctance to be involved in TEAMS was due to stakeholder discomfort with the exposure of their data. A major data collection challenge was obtaining a geo-referenced inventory of the assets, so an integrated data collection process was developed using photogrammetry, GPS and innovative field data collection techniques.

One important benefit of a web-enabled tool such as TEAMS is reduced system maintenance cost, since industry standard programming languages are used. It also is easier to adjust to the number of users since web-browser software is the only desktop requirement. The web also allows for low-cost seamless integration of data and security, since industry standard protocols were used. The major downside of web-enabled tools is they require a robust supporting network.

Important lessons learned in the course of the TEAMS project include: the need to develop and document a detailed work process, communicate this to staff, and follow through with it; the benefits of employing flexible and low-cost workers; the value of maintaining a detailed schedule; and the need to regularly report and communicate results to stakeholders.

■ Future Plans

Version 8V05 of TEAMS is currently available and being used by Turnpike Enterprise personnel. The initial Phase I release of TEAMS is to be completed in the summer of 2003. The agency will obtain feedback from users to plan for the following phases. The next version will fully integrate databases of Turnpike utility and toll data. Other potential enhancements include integration with the maintenance management system.

A schedule has not yet been established for the next phases of enhancements. However, support and resources are available within the agency to proceed with this data integration process.

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■ Acknowledgment

Information for this detailed review was compiled with the assistance of William Thorp, Florida's Turnpike Enterprise Chief Financial Officer, and Jesse Day of PBS&J.

Hawaii DOT Coordinated Data System/GIS

History/Background

A major data integration initiative at the Hawaii DOT (HDOT) was the development of a Coordinated Data System/Geographic Information System (CDS/GIS). The HDOT Planning Branch initiated this effort in 1996 in response to the agency's need to collect, manage, and disseminate data more effectively, and to improve the efficiency with which it generates Federal and state-mandated reports. For example, before the CDS/GIS was developed, inventory data were incomplete and difficult to access. Straight-Line Diagrams (SLD), the Planning Branch's main tool for reporting the mile point locations of key features along Hawaii's highways, took months to generate. HDOT's vision for the CDS/GIS is to integrate enterprise-wide information required to support the entire life cycle of Hawaii's highway infrastructure.

Integrated Data Considerations

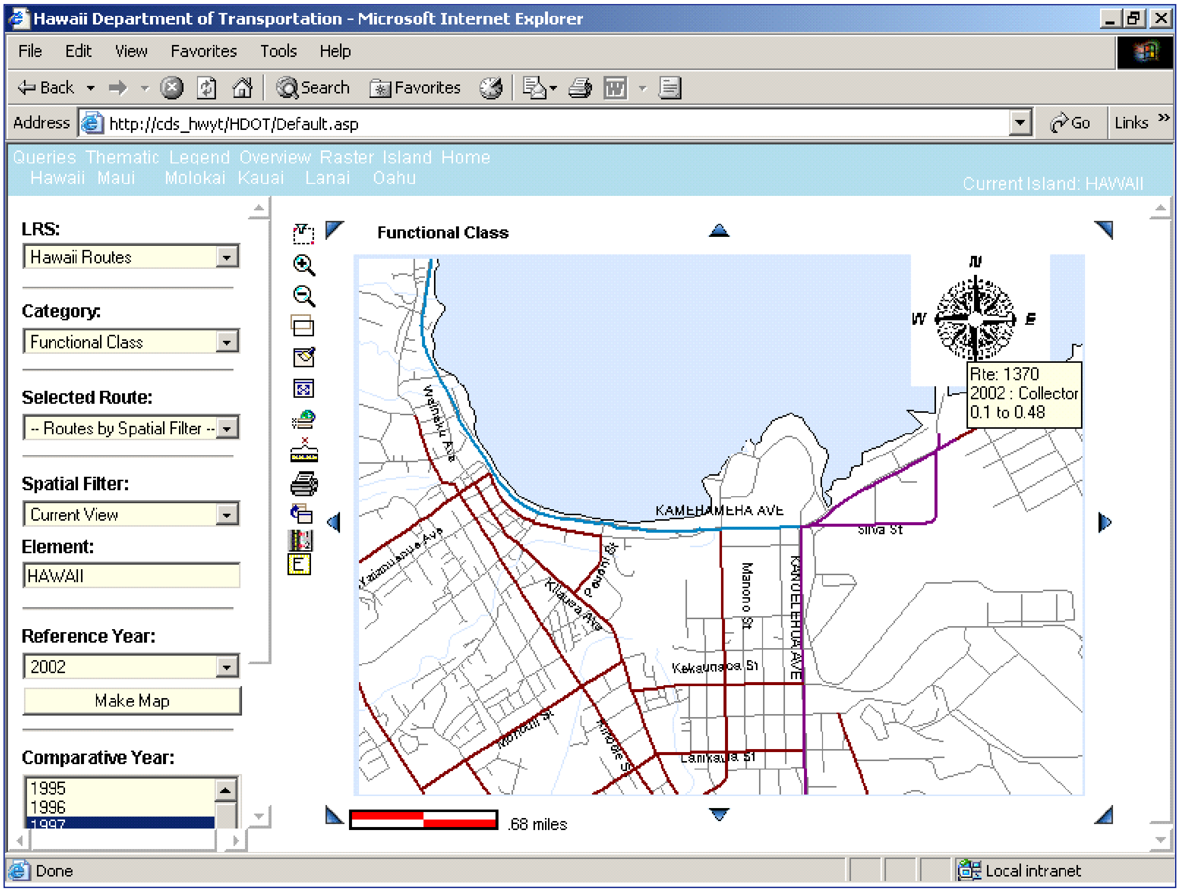
The CDS/GIS integrates a wide range of data from several stand-alone data sets. The system provides a single source for historic pavement data required for HPMS reporting, bridge data required for National Bridge Inventory (NBI) reporting, highway inventory data (e.g., guardrails, light posts, signs, etc.), traffic data, and current and historic project data. The system integrates data from relational databases, isolated spreadsheets, and videolog files.

All data referenced in the CDS/GIS uses a system of routes and mileposts. Geographic referencing was not a major issue during the integration effort because the legacy data were largely based on this common referencing system.

HDOT staff can access CDS/GIS data using a web-enabled map-based query tool illustrated in Figure 1. In addition, HDOT's Highway Performance Monitoring System (HPMS) and Traffic Management System can access data from the system.

The CDS/GIS primary mission is to support HDOT's planning and design functions. However, the system also is frequently used to support operations and maintenance. In addition, HDOT managers use the CDS/GIS to respond to specific requests for information regarding certain facilities.

Figure 1. CDS/GIS Interface



■ Integrated Data Architecture

CDS/GIS data is stored in a single normalized data warehouse. Data is transferred to and from the database using a Microsoft Access interface and open database connectivity (ODBC) protocol. An objective of the integration was to make the agency's workflow more efficient, not to change it. Therefore, various parties throughout HDOT are still responsible for collecting and maintaining data, while the CDS/GIS is now the official repository of these data.

The CDS/GIS relies extensively on off-the-shelf software including Oracle 8.1.7 and standard mapping software. As the agency's first major enterprise-wide data initiative, the CDS/GIS project established an enterprise data dictionary and information technology (IT) standards for future applications. The use of off-the-shelf software and widely accepted IT protocols will enable future systems to be integrated with the CDS/GIS.

Lessons Learned

One of the biggest organizational challenges throughout the development of the CDS/GIS was the wide mix of IT experience among HDOT staff. Efforts were made to include representatives from across the agency in the development process, but at times it was difficult for project staff to communicate the practical and technical implications of meeting everyone's expectations for the system. It also was difficult to communicate the full capabilities of a future system and to illustrate how it could eventually support and enhance existing business processes. Project staff found that it was much easier to generate interest after the system was complete, when concrete demonstrations were possible.

During the needs assessment phase of the project, detailed knowledge of various aspects of HDOT was required. Designing a system to support functions that reach across the entire life cycle of the agency's assets requires project staff to understand clearly its various organizational structures, business practices, management cultures, funding environments, and technological capabilities.

From a technical point-of-view, the agency's decision to rely heavily on off-the-shelf software components and industry standards was a critical success factor. Project staff also leveraged the continual advancements in technology over the course of the project. Major technical hurdles that were identified when the project began in 1996 were addressed with standard software solutions just five years later.

Future Plans

HDOT's plans for the future are currently in a state of flux due to budget uncertainties. However, the CDS/GIS project has established a solid foundation for future IT efforts. As applications are developed to support the agency's business practices, they will be integrated with CDS/GIS. For example, the HDOT is implementing a videolog inventory system that will improve the efficiency of its maintenance operations. This system is consistent with the IT standards established throughout the CDS/GIS project and will be integrated with the data warehouse. Other potential future initiatives at HDOT include development of a comprehensive pavement management system and full implementation of the agency's bridge management system.

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Acknowledgment

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Iowa DOT Coordinated Transportation Analysis and Management System

■ History/Background

A major data integration effort is underway at the Iowa DOT (IDOT): the development and implementation of a Coordinated Transportation Analysis and Management System (CTAMS). The goal of this initiative is to support the agency's decision-making processes by improving the integration of existing data using a linear referencing system (LRS) as the common link.

In 1995, IDOT adopted a Geographic System Strategic Plan. Based on this guidance, the Office of Transportation Data created an LRS Team and hired a full-time GIS coordinator. At the time, transportation data was stored throughout the agency in various stand-alone legacy systems and was referenced using a number of linear referencing methods (LRM). In response to the agency's desire to integrate this data, the LRS Team recommended the LRS project. The objectives of the initiative include:

- Integrate Iowa DOT's legacy referencing models (e.g., mileposts, stationing, reference post, etc.);
- Develop and maintain a new linear datum;
- Maintain existing linear datum;
- Ensure existing LRM data integrity;
- Enable maintenance of LRMs over time based on defined standards;
- Integrate linear locations defined for all modes of transportation (e.g., roadway, rail, air, water, transit, and pedestrian);
- Integrate spatial data with linear-referenced data;
- Resolve temporal data integrity issues;
- Provide customers with data access and reporting tools; and
- Develop an LRS that is scalable to all road systems, modes, and information systems.

The project began in 1999 with the development of conceptual, logical, and physical designs. These designs are based on the guidance developed through National Cooperative Highway Research Program (NCHRP) Project 20-27(2), *Adaptation of Geographic Information System for Transportation.* In April 2000, a pilot study was initiated to validate these designs. Implementation, which is currently underway, consists of four phases, with the final phase scheduled for completion in June 2005.

The project team includes a project sponsor (the Director of Information Technology Division), two project managers, a core team, a steering committee, a technical advisory team, Iowa business/subject matter experts, and a team of consultants. The steering committee includes representatives from across the agency (e.g., Planning, Motor Vehicle, Highway, and Information Technology Divisions).

Integrated Data Considerations

Potential users from across the DOT were identified during the needs assessment phase of the project. The Highway Division is responsible for the agency's management systems (PMS, BMS, MMS, Safety Management System, and Resource Management System), and Intelligent Transportation Systems. Each of these systems includes an LRM component. The LRS will enable integration of the data in each of these systems. The Planning and Programming Division is responsible for the agency's roadway inventories and will use the system to perform needs assessments, produce sufficiency reports, generate programming reports and maps, access roadway inventory, and perform trip generation analyses. The Motor Vehicle Division will use the system for tracking crash locations, integrating safety data, routing trucks, and routing emergency vehicles. In addition, the system will provide a foundation for integrating transit data for the Modal Division and enable the director's staff to quickly access engineering data. The system will provide ready access to the business data required to support each of these functions.

The LRS will be used to integrate data from relational databases, video log inventories, and data collected with global positioning systems (GPS). Sources of this data include: Geographic Information Management System (GIMS) (the DOT's primary GIS road inventory database), Pavement Management Information System (PMIS), Highway Performance Monitoring System (HPMS), RoadView System (video log inventory), and Accident Location and Analysis System (ALAS). These data are currently referenced using six different LRMs: segments, reference post, stationing, literal description, milepoint, and coordinate route. The data will be integrated through the use of a series of algorithms that translate between each of these methods. In essence, there will be no "standard" referencing system. Rather, the system will be able to translate data referenced with any of these six LRMs to any other LRM.

Integrated Data Architecture

Figure 1 represents the conceptual architecture for this data integration effort. It is consistent with the framework developed through NCHRP Project 20-27. Integrated data will be maintained in legacy systems. This data will be processed with a set of LRS routines, integrated, and stored in a data library. Users will access the data library using a number of client applications including GIS clients, database reporting tools, web-based application clients, and command line database interfaces. In addition, some of the systems that provide the initial data (e.g., PMIS) will access the data warehouse.

Figure 1. Conceptual Architecture

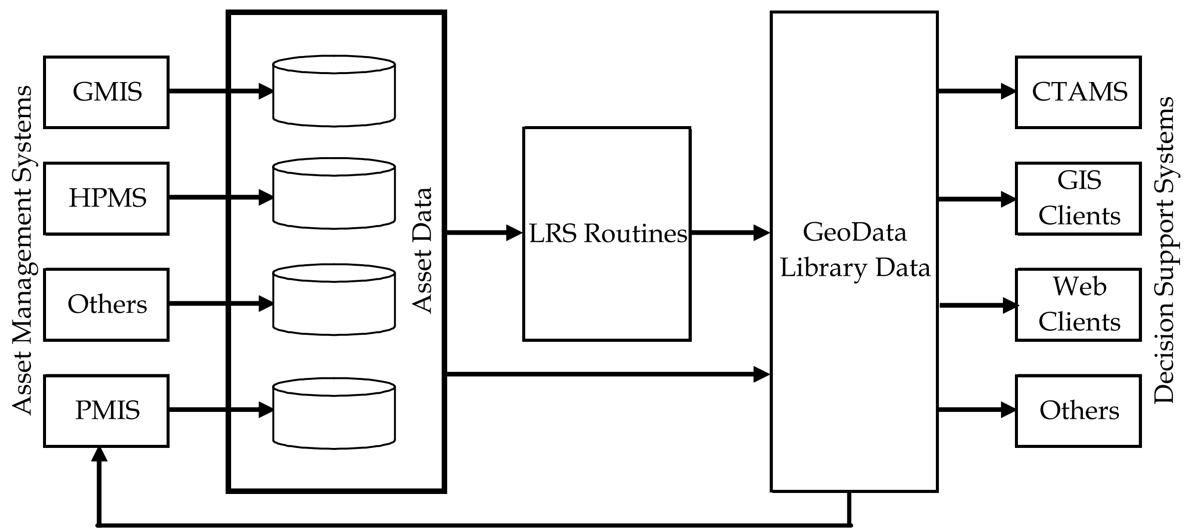
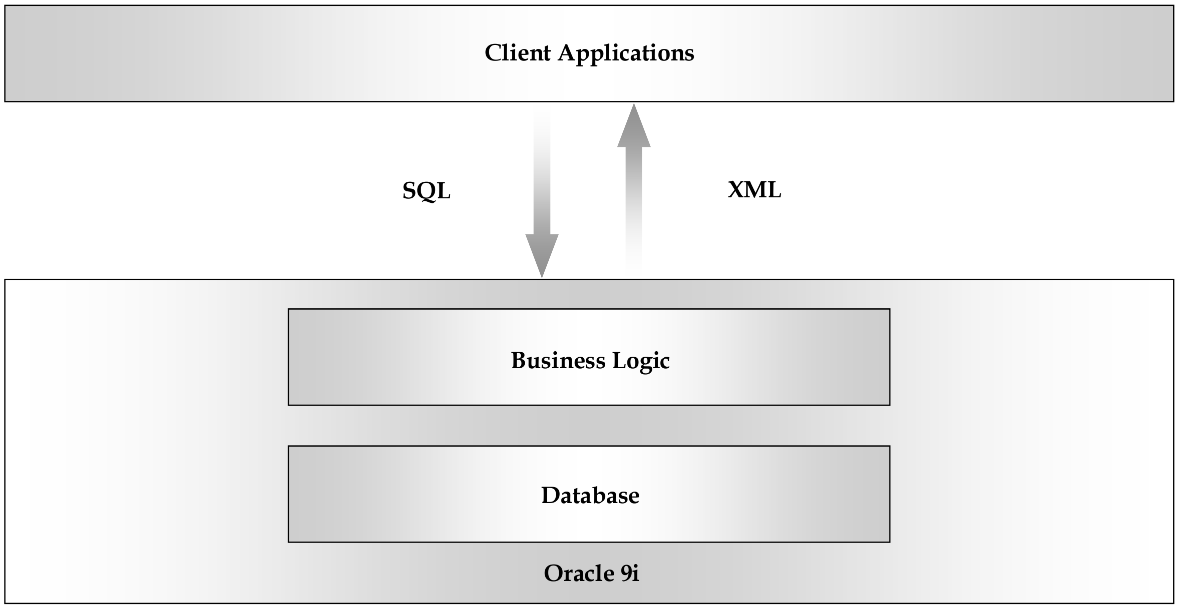


Figure 2 summarizes the implementation architecture of the integration effort. The business logic and database components are encompassed in the Oracle 9i environment. Client applications download and upload data using Structured Query Language (SQL) and Extensible Markup Language (XML) protocols, respectively. This implementation strategy is consistent with IDOT's current IT standards.

Figure 2. Implementation Architecture



Lessons Learned

IDOT has developed and tested a practical approach to applying the framework presented in NCHRP Project 20-27. A pilot study involving data from two counties confirmed that the proposed approach will work and that the various levels of data accuracy required for business processes throughout the agency are achievable.

Based on the findings from the pilot study, IDOT has decided that data collection will be contracted out to staff that will be on site at IDOT, with direct oversight provided by IDOT. Internal staff will perform data maintenance. A temporary increase in staff will be required for the initial effort.

Implementation challenges include working with legacy clients and legacy structured data, and enabling the system to operate on the Internet. Industry standard protocols, a multi-tier application, a database centric design, standard languages, and vendor independent components helped address these problems.

Future Plans

IDOT has partnered with the Des Moines metropolitan counties to develop a road centerline database that will be used for their emergency response system. All public roads in a four-county area were collected. In addition, all Interstate highways, U.S. highways, and state routes in Iowa will be incorporated in the new LRS data model by the end of fiscal year 2003. The DOT is working with local governments to develop partnerships for maintenance of the statewide road database, and has been collaborating with the U.S. Census Bureau to coordinate the collection/creation of the 2010 Iowa Topologically Integrated Geographic Encoding and Reference (TIGER) data. These initiatives have led to the development of an Address Range LRM.

The first production version of the LRS Maintenance Application will be completed in November 2003. This tool will help both the Iowa DOT and local governments maintain the database. Special emphasis is being placed on the ability to maintain the temporal components of the database. It is important for the system to know when the roads are opened to traffic and retired from the network so business data can be accurately mapped against the road centerlines. Work remaining on this initiative includes developing and supporting the integration of user applications (including the LRS enabled CTAMS). This work will be implemented in phases. Each phase will integrate more data and address a larger number of LRMs. As part of this work, a new Literal Description LRM is included to allow a textural description of a location.

The data integration project will support the following strategic agency initiatives and industry trends:

- Movement toward an Asset Management approach that identifies and evaluates existing assets and investment alternatives and enables decision-makers to arrive at decisions that represent the best value and maximize return on investment;
- Establishment of performance measures and the need to tie costs to asset performance;
- Need to improve the efficiency with which maintenance staff collect data and track work accomplishments;
- Multiple levels of decision-making within the agency (e.g., enterprise level, system level, program level, and project level); and
- Increased outsourcing and customer-focus that require IDOT to interact with a large number of external parties (e.g., partners, contractors, customers, competitors, and suppliers).

In response to these items, the data integration effort will support asset identification, location, and condition assessment over time; pursue interoperable approaches; improve operations, decision support, and data distribution; focus on LRS benchmarks related to maintenance functions; and minimize the impacts on existing business processes.

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Acknowledgment

Information for this detailed review was compiled with the assistance of William Schuman, GIS Coordinator, Iowa DOT.

Kansas DOT Enterprise Data Architecture

History/Background

The Kansas Department of Transportation (KDOT) has a strong Information Technology (IT) department with several related initiatives that are moving the agency toward an integrated data environment to support multi-level decision-making. The IT department emphasizes the importance of coordinating strategic IT planning with architecture planning and project plans. KDOT has been working toward an Enterprise Architecture (EA) since 1989 when focus on data and information was emphasized through an Information Engineering initiative. An Enterprise Architecture is a framework that allows for capture and maintenance of high-level information, business concerns, and strategies. It is the underlying base to support technology management, data management, portfolio management, Asset Management and technology management. EA includes a hierarchy of views pertaining to enterprise data, processes and network elements.

KDOT also has a GIS application development effort underway. GIS will serve as the user interface for the overall integration effort. The system, developed in 1990, undergoes continuous updates and upgrades. A GIS Strategic Plan for KDOT was developed by Geo Decisions in 2000. The purpose of the plan was to define and document KDOT's planned GIS direction for the next several years. This plan updated an earlier "GIS Directions Report" that was developed in 1995 by taking into consideration emerging technologies and new agency needs. It takes into account critical organizational, mapping, and technological issues facing the agency.

Three levels of IT committees – executive, middle management, and working – are used to manage all IT initiatives in KDOT.

Integrated Data Considerations

KDOT plans to integrate all data using EA as the framework. By mid 2003, the Logical Data architecture, which is the first stage of the project, will be complete. Application portfolios will be developed including the integration of the various management systems such as accident records and PONTIS. KDOT owns all data that will be integrated. The priority and subsequent funding for the next stages will occur later as part of KDOT's project prioritization process. Eventually the application will support all planning, operations, and infrastructure functions.

The data sets currently reside in a variety of formats such as flat files and relational databases.

The planned 1:12,000 basemap will form the basis for the common location reference system for the EA. KDOT has recently realigned the basemap using centerlines calculated from latitude and longitude collected using GPS technology. Intersection breaks are currently being added to the basemap. KDOT uses its adopted Route County Logpoint as the referencing system for all of its GIS applications. Transportation data and associated metadata is stored across the Data Access and Support Center (DASC), the statewide GIS clearinghouse for data sharing.

Integrated Data Architecture

KDOT uses LAN and TCP/IP for computer communications and GIS access. Oracle is used as the standard database.

KDOT is currently deciding on a platform for EA. The agency is considering IBM, Oracle and Microsoft products. It plans to use Proforma Corp's ProVision as an EA tool. KDOT is using Highways by Exor for its master highway database.

Lessons Learned

Some of the lessons learned by KDOT in the development of the EA include:

- They have more systems (88+), databases (56), and technologies (250+) than expected;
- The relationships between systems, databases and technologies are more complex than perceived;
- More information goes to the public than perceived; and
- There is a great deal of redundancy in both data and technology.

Challenges encountered include:

- Lack of funding to support the entire project;
- Difficulty making a decision regarding the tools to use for the EA;
- Difficulty convincing data owners to let go of data as they feel there are no incentives to sharing and their data could be criticized;
- Lack of ownership of data; and
- Middle management resistance within KDOT.

Lessons to be passed on to other organizations include:

- Ensure that the organization's project management structure includes all levels of staff within the department;
- Hire an experienced consultant to provide knowledge, advice, and mentoring;
- Create an environment that supports process driven activities;
- Take an incremental approach Perform one data integration step well, secure the benefits, and then move to the next step;
- Build on data itself; keep it flowing;
- Remember that the benefits of integration will lag its implementation;
- At some point there are diminishing returns from integration;
- Pursue major steps create a basic infrastructure for data during good fiscal times, then make incremental improvements; and
- Be sure that success does not limit future success. For example, do not let it be "good enough."

Future Plans

One of KDOT's first steps toward an Asset Management system will be an information portal, a web-based application consisting of a data warehouse and GIS front end. This project will permit: an enterprise view of the system, an examination of changes in conditions, and decision-making capability related to resource allocation. This project will break down the stovepipes of applications currently residing within KDOT. Future EA project portfolios will be more ambitious as KDOT continues to build the architecture.

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Acknowledgment

Information for this case study was compiled with the assistance of Ben Nelson, Bill Roth and Kelly Badenoch, Computer Services, Kansas DOT.

Maine DOT Data Warehouse

History/Background

Maine Department of Transportation first established an integrated database of highway information in the early 1970s called TINIS (Transportation Integrated Network Information System). It contained data that was geographically referenced to a common link-node system. Maine DOT did extensive work in the 1990s to develop a GIS base map from digitized USGS maps, tying the TINIS node identifiers into the base map, and building an ArcInfo route system to represent the TINIS links. This work allowed the agency to perform dynamic segmentation and overlay link-node referenced data from TINIS (e.g., functional class) with route mile point referenced data (e.g., culvert locations).

In 1998, a new GIS-Enabled data warehouse system called TIDE (Transportation Information for Decision Enhancement) was put into place to take advantage of the GIS work that had been accomplished and provide wide access to transportation data for analysis and reporting purposes. Today, a new initiative is underway to develop a locational referencing management system transportation solution and migrate the mainframe-based TINIS data into relational databases. The new system is called METRNS, Maine's Network Transportation Solution.

Integrated Data Considerations

TIDE provides access to the core data sets in TINIS, which include highway inventory data, bridge inventory data, traffic and accident data, railroad crossings, project history data and HPMS data. It also includes data from the pavement management system. TIDE provides *ad hoc* query and reporting capabilities, both tabular and map-based. It has been used for a number of ongoing and specialized analysis tasks including highway needs and adequacy reporting, trend analysis, safety analysis, and local road assistance queries.

TIDE supports queries of data stored in both of the primary referencing systems: the link-node system used in TINIS, and the route-milepost system used by other data sets. However, given the capabilities of the *ad hoc* query tool used for the system, TIDE uses a "static segmentation" approach, which involves breaking the highway network into homogeneous segments based on the values of over 100 different attributes. The static segments are generated on a weekly basis, and the system is loaded with updated attribute data for each of these segments.

While TIDE has provided significant value to Maine DOT, the agency is now moving forward with a new effort to allow the system to incorporate additional data. While the agency does maintain a master geography file using ArcInfo, including capabilities to overlay data from the two linear referencing systems, linear referencing information in many data sets have not been kept in synch with these master geography files, as changes to the highway network have occurred. This includes information on culverts, guardrail, signs, signals, right-of-way (ROW) permits, maintenance activities, capital projects (requests, candidates and programmed projects from the ProjEx project management system), as well as subsets of information from the bridge and safety management systems. A common linear referencing engine is being provided that will be used to keep all geographically based data in the department in synch as changes are made to the roadway network. This engine will allow more accurate data integration than that offered by the current systems, and will provide the capability to correctly maintain historical data location references.

Integrated Data Architecture

TIDE uses an Oracle relational database integrated with ESRI's ArcView GIS query and display tools. TIDE's ad hoc query and reporting functionality is provided via an off-the-shelf package (Hummingbird's BI-Query). Additional spatial query and mapping capabilities are provided using ArcView.

Maine DOT makes some use of Citrix software, an enterprise database access product that provides secure, easy access to comprehensive information resources from any location, to serve ArcView licenses and to provide TIDE access to external agencies.

TINIS data is currently still maintained on the mainframe, and imported into TIDE on a weekly basis. However, all TINIS data are scheduled for migration to relational databases. Maine DOT has contracted with Exor Corporation to provide the location reference engine and to serve as the master highway database. Two Exor products have been purchased the Network Manager (the core highway database and linear referencing information), and the Spatial Data Manager (ArcView application for GIS data management, query, display and reporting). The master highway inventory data, HPMS data, railroad crossings, traffic and speed zone data will be migrated into Exor and maintained there. Pavement, bridge, accident data, maintenance management data, and project data will be maintained in separate databases external to Exor. However, these databases will all rely on Exor for maintenance of geographic referencing information. TIDE will continue to function as the data warehouse, but it will receive data from Exor and the other systems of record rather than from TINIS.

Lessons Learned

Maine DOT cited several lessons learned in a presentation at the 2001 FHWA Data Integration Peer Exchange. These lessons are paraphrased below:

- No single location referencing method served all the data managers well. Therefore, rather than requiring everyone to adopt a single method, the agency is relying on mechanisms to allow location synchronization and cross-referencing of information collected with different referencing methods.

- The Information Systems (IS) staff should work in partnership with other agency staff to promote data integration. However, they must recognize that in some cases department employees need to develop separate databases in order to do their jobs. Specific IS roles include development of an Enterprise Information marketing strategy to make employees aware of available data and the benefits of integration, providing advice and support on collection and use of data; and early, substantive involvement in new application development projects – particularly those involving outside contractors.

- Data should be collected electronically as close to the source as possible in order to best preserve data integrity.

- Data should be made widely available. This will discourage others from creating redundant data collection procedures and databases.

- An ongoing modernization strategy should be employed so that systems in place are do not lag behind current technology.

Future Plans

Maine DOT plans to completely implement of METRANS by October 2003. The effort to migrate data out of TINIS will be completed several months later. Future plans include migration of the data into Oracle Spatial (the next version of Exor is expected to support this database), and eventual implementation of a web interface to TIDE.

Maine DOT has established the following basic principles in support of its future data integration efforts:

- Official data owners are designated responsible for the currency, integrity, and availability of data elements;

- Data is to be captured electronically as close to the source as feasible to ensure efficient capture and accurate data;

- All data in the department that is geographic in nature will be geo-referenced and integrated by location;

- Each data element is to be documented to promote appropriate use;

- Oracle relational database technology is the current data management method of choice for any multi-user data;

- Enterprise-wide information systems are fostered by coordinating IS across the department; and
- New systems initiatives are sponsored and managed by the user community, in close partnership with the Information Systems staff.

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Acknowledgment

Information for this detailed review was compiled with the assistance of Nancy Armentrout, Maine Department of Transportation.

Michigan DOT Transportation Management System

History/Background

The Michigan Department of Transportation (MDOT) began its formal focus on data integration as part of its commitment to build a Transportation Management System (TMS) that responded to the requirements of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. The ISTEA legislation provided the initial impetus for what was to become a massive redesign of how the MDOT did business and, specifically, how it handled data. MDOT realized that its legacy systems could not be modified to meet the ISTEA requirements; it undertook a radical redesign of the business processes and the software and data systems that supported that business.

In the early 1990s, MDOT was anxious to replace an aging mainframe system. Since the software on that mainframe could not be modified to support the new processes, the then-emerging client-server technology was selected by MDOT to replace its mainframe platform. MDOT embraced the client-server technology and relational databases as the future of MDOT operations.

The integration efforts began in 1993 with a Business Process Redesign of MDOT's core and support businesses. Initial efforts were focused on MDOT's software and processes that supported project and program development. As the examination of those processes progressed, MDOT discovered that much of the information needed was contained in four large data files which contained essentially the same information, but which were stored and accessed in different ways. Reconciling these different storage methods and definitions would allow MDOT to eliminate several legacy applications and reduce multitudes of procedures down to two major applications – MDOT's Financial Obligation System (MFOS) and the Michigan Project Information System (MPINS) – and one database, while significantly improving data quality. MFOS and MPINS support the planning, monitoring, scheduling, and funding of project development activities through construction contract lettings.

Next, MDOT developed prototypes for the various internal management systems, including bridge, pavement, congestion, intermodal, transit, safety, and traffic monitoring. Three other systems were prototyped but not implemented. The third phase was system and database design in 1994 and the final development and rollout occurred through 1996. The development process involved a combined top down and bottom up approach to create a new business culture within MDOT. The process was designed to identify, review, and reengineer the existing business processes within MDOT, identify the users of the system globally, establish the overall data needs of the process owners and to facilitate a fully decentralized set of planning and programming processes. It became clear immediately that the establishment of an open system client/server architecture would facilitate decision-making in a more decentralized and flattened organization that was central to the overall success of this agencywide restructuring. This effort set the stage for the development of MDOT's first business plan by allowing the shared and focused measurement of the goal and objectives established in the plan.

The TMS itself was designed as one integrated application, with one integrated database. The development process was a joint effort between the consultant community and the various business and process owners at MDOT. Over the life of the project, and especially during the prototyping phase, over 500 department employees were part of the process (a critical mass of over 20 percent). The decision to build a new client/server TMS was predicated on the top management seeing the ISTEA legislation as an effective "change agent" within MDOT. The use of Federal funds for the development of the TMS process was continued even after the mandatory language for the six systems was removed in 1995. The decision to build a new application was made by top management based on the determination that no existing non-proprietary management or analysis packages satisfied the requirements MDOT had established.

Integrated Data Considerations

MDOT's integration process addressed the lack of standards for data quality, several common referencing systems, the lack of agency data model, and the absence of an agencywide data administrator. For data to be the "corporate asset," it must be managed and agreed to by the business process owners. In all cases, the business needs drove the MDOT data integration effort, not the reverse. A key to making this happen at MDOT was the Michigan Architecture Project (MAP). This activity did not address process relationships, but the day-to-day data needs for managing the project development, financial obligation, and construction estimates. The MAP process found that 75 to 80 percent of the data was duplicated across four data application areas.

MDOT adopted four guiding principles identified by the National Performance Review for gathering data needed to support an integrated Asset Management process. Data gathering must be focused, flexible, meaningful, and consistent. The standard was to collect once, store once and use many times. The combination of the TMS and MAP processes has resulted in the reduction of approximately 20,000 files to five major databases maintained and populated by MDOT. The MAP process developed the data modeling and naming standards and quality assurance and configuration management requirements necessary to assure the users and decision-makers of the accuracy and timeliness of the data.

The most critical activity of the data integration process was identifying and defining which data already being collected should be continued, which should be dropped, and what new data might be important to collect to meet the goals of the integration effort. It was agreed that every piece of data must have an owner without whom it could not possibly function. Information that was not identified as being important would not be included in the new relational database. All of the business process owners at MDOT were required to follow this guideline for the TMS development process. Limiting original data collection, adopting sampling and quality standards, and agreeing on common data and attribute definitions were key to controlling the costs of original collection and eliminating duplicate storage, and prompted MDOT to establish corporate data standards.

MDOT's ability to integrate the various asset databases was facilitated by the decision to abandon all the existing (and inconsistent) linear referencing systems used within the agency and adopt a single, statewide linear referencing system. The single referencing system allowed consistency among many key data components and permitted sharing among county and city road agencies and the state police. To implement this referencing system MDOT worked with, and funded the development of, a statewide GIS capability with the Michigan Department of Management and Budget's Center for Geographic Information. This relationship leveraged the latest GIS and GPS technology to develop a statewide GIS base map used by all state departments. It produced, for MDOT, a complete road referencing system upon which all transportation features could be referenced.

On a statewide basis, this multi-agency partnership eliminated many of the processing steps that occur between the data capture, the integration into appropriate shared databases, and its final use or dissemination across state government. For example, the need for the state to acquire more than one set of census data has been eliminated. It also provides the common reference map for condition and program reporting and strategic investment strategies for Michigan's new statewide Asset Management legislation. The final agreement on a common referencing protocol for all transportation-related assets has allowed a common base map to be established across state government, and between state, local, and Federal agencies.

Integrated Data Architecture

The integration effort involved migration of all key MDOT planning, programming and data collection and storage applications from a mainframe to client-server/open system environment. It also established direct support and linkage to MFOS and MPINS. Underlying these two systems is a single database containing all of the data necessary to administer a program and project development operation.

TMS operates in a client server environment using UNIX servers and Oracle databases. The system was programmed using the PowerBuilder development software. TMS provides ad hoc queries using the Sybase InfoMaker tool, although any tool supporting ODBC connections can be used. Maptitude is supported for the GIS queries. Other software may be used in business areas to support lower-level data preparation tasks. For example, the traffic data information system uses FoxPro to prepare data for and to retrieve data from the TMS.

TMS was intended to be a single integrated application. The final product requires MDOT staff and remote users to access the system to run all Asset Management or analysis programs available at MDOT. This has created a clear understanding across the various business areas of the information available to all users, and has facilitated an integrated data analysis process within and among the various systems, including:

- **Pavement Management System (PMS) –** This system interacts with the internally developed Road Quality Forecasting Systems, the statewide pavement distress data, and the pavement condition history file. It also can relate to the Pavement Surface Evaluation and Rating System (PASER) and the RoadSoft pavement management tool.

- **Bridge Management System (BMS) –** This system contains all required National Bridge Inventory (NBI) data elements. The AASHTO PONTIS analysis capability is embedded and the PONTIS data structures have been incorporated completely into the TMS database.

- **Congestion Management System (CMS) –** The internal analysis is supported by TransCAD. The users can coordinate with the statewide and MPO transportation demand estimation modeling systems.

- **Safety Management System (SMS) –** Crash and roadway information is available in detail, enabling time of return, crash reporting, high-crash locations, and other analysis to be performed when determining the potential safety benefits of projects.

- **Public Transit Management System (PTMS) –** Allows local transit agencies to input operating assistance and grant applications, financial statements and usage reporting, and performance characteristics.

- **Intermodal Management System (IMS) –** Allows access to airport, carpool, parking lot, intercity transportation, and rail facility statistics, as well as to pipeline and other non-highway transportation features.

- **Traffic Monitoring System –** While this system is not embedded in the TMS, it employs the shared data principles used to design and implement the MPINS and MFOS systems.

The TMS data and analysis results can be displayed using the GIS and spatial database capabilities developed in cooperation with the Michigan Center for Geographic Information's statewide GIS roadway base map. The relationship with Michigan's statewide GIS base map leverages many other attributes needed for integrated transportation decision-making, identifies responsibility for long-term maintenance and updating of the map and data sets, and embeds MDOT's common referencing system roadways as the standard for all transportation providers and planning agencies.

■ Lessons Learned

The TMS directly meets the day-to-day business needs of the system users. It sets the MDOT baseline for data quality and timeliness and for asset condition and service levels for use in program and project decision-making and strategic asset investment targets. Major accomplishments with respect to data integration were as follows:

- Substantial elimination of the duplication of data collection activities;

- Improved understanding of the criticality of quality data in the program and project decision-making and priority determination process;

- Substantial agreement among the users on a single definition of key data elements to be input into the system. This has been enforced by MDOT's central IT operation; and

- Extensive sharing of data and analysis tools among all internal and external users of the system.

The TMS integration effort, combined with the move to the client-server, and open systems computing environment, provided a solid basis for MDOT to reevaluate its business process relationships, to identify and define key data needs, break down existing stovepipes, and empower individual employees. A successful part of the integration effort was MDOT's assignment of the IT staff responsible for maintaining and enhancing the software to work side-by-side with the business process owners and users.

The TMS development effort did encounter difficulties not uncommon to large-scale efforts of this nature. First, considerable time elapsed between project's conception and its delivery. The enthusiasm, focus, and buy-in that were established among the users during the early project conception process were difficult to sustain throughout the development process. Much of the initiative taken and progress created by the business process owners through the prototyping activity was lost and, in most cases, had to be reestablished at the rollout, often with new staff.

MDOT faced a variety of technical challenges. Some work was delayed due to the need to wait until the NT operating system was made available for use in the development. Additionally, an embedded GIS functionality was envisioned which the marketplace had not yet produced. This resulted in higher development costs and delays, and the functionality was never ultimately delivered.

At the time the TMS was developed, MDOT had to break new ground; no suitable off-the-shelf solutions were available. Today, many more mature products are available to facilitate the integration and analysis requirements for Asset Management activities. MDOT would likely not attempt to develop its own system if it were starting out today. To address the scope creep that can be a major problem associated with undertakings of this scale, MDOT instituted new project management tools and internal controls to keep projects on schedule and within budget.

Finally, MDOT learned that it is one thing to develop an integrated system of database(s) and applications, and yet another to maintain that environment so it can meet evolving business and technology needs. There must to be a commitment to solve business problems with new or emerging technologies, in contrast to maintaining the software in its original form. This is both a business and a technical problem. The business cannot think a system is "done" once it is operational and proceed to neglect its maintenance. Similarly, the business needs to make sure that the technical side of the operation, specifically the IT component, stays current with the existing and emerging technologies. It is much easier and cheaper to stay current than it is to catch up. The information systems staff needs to be proactive to keep the software functional and current not only from a technical standpoint, but also from a user's perspective.

Critical is a methodology to design databases and applications that are flexible enough to accommodate the changing data requirements of the user. It also is important to ensure that users have sufficient training to understand how to use the tools provided. Keeping the system users' needs satisfied is the only way to sustain the shared data concept in any agency. This will prevent users from going "outside" of the systems because they do not understand or cannot use the data of the database environment. A combination of education and facilitation to make the systems and databases user friendly must be embedded in the maintenance process.

Future Plans

In 2002, the State of Michigan passed Act 499 that requires its transportation industry to adopt Asset Management concepts. Agencies must initially report to the legislature the condition and service levels of the all Federal-aid eligible roads and bridges, report the three-year road and bridge program of projects for all state, county, and city agencies, and develop performance-based strategic investment strategies for condition and service targets. This requires the integrated database and single base map activities initiated at MDOT to be maintained and extended. Defining the data elements and collection techniques necessary to assist in determining the life cycle of various capital and maintenance treatments is also key. In addition, the need to have good financial data available to develop programs to meet established condition targets will require close integration between the financial databases and traditional transportation data.

MDOT also is currently in the process of implementing web-based front ends to selected applications. For example, the Public Transportation Management System and the bridge inspection processes are currently being migrated to the web. Such migrations in the presentation and functionality levels can be performed with minimal or no database changes. Neither system will require database changes other than accommodation of a new security model.

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Acknowledgment

Information for this detailed review was compiled with the assistance of Ron Vibbert, Manager, Asset Management Section, Bureau of Transportation Planning, Michigan Department of Transportation.

Minnesota DOT Transportation Information System

History/Background

Minnesota DOT (Mn/DOT) has several data integration initiatives underway including the development of a Location Data Model (LDM) and a Transportation Information System GIS tool (TIS Project 274). This review focuses on both initiatives by the Office of Transportation Data and Analysis and the GIS Support Section which provide reliable and up-to-date data for the state's transportation system.

LDM is designed to provide centrally managed location information and to develop tools capable of editing and displaying stored data. TIS Project 274 is developing a GIS application tool that can be used to access and view data from Mn/DOT's Oracle-based TIS. These two projects have been combined and are being undertaken simultaneously. The results of these efforts include a stable common referencing system for location-based data within Mn/DOT and a data warehouse to store and access state transportation data.

The LDM project was initiated to address several data issues. For example, many data sets existed with various location identifiers and linear referencing systems (narrative descriptions versus route reference and offset), making it difficult to integrate data. Much of the summary data on roadway characteristics, traffic volumes, crashes, railroad crossings, pavements, and bridges were contained in a legacy, mainframe system that was developed more than 20 years ago. The system lacked adequate mapping and display capabilities and could not track historical trends, or identify programmed/proposed infrastructure changes. In addition, reporting was difficult for all but high-end users. Mn/DOT hired Bentley Transportation in 1999 to assist with the design and construction of a model and application to resolve these issues.

LDM is intended to:

- Create a single stable linear location method (linear datum) to be used to identify locations of transportation facilities throughout the State;
- Create well-defined processes and standards for linear datum maintenance and access to locational information;
- Provide the capacity for non-Mn/DOT transportation facility owners to provide input to the linear datum;
- Prepare for maintaining and reporting road inventory and other route reference point-based data using maps (digital and hardcopy); and
- Prepare for applications that analyze multimodal transportation systems for performance and needs and for evaluating potential investments in those systems.

Integrated Data Considerations

The LDM and TIS Project 274 work together to meet Mn/DOT's data integration goals. When complete the LDM will provide access to TIS as well as data on ramps, loops, highway collectors, distributors, railways, commercial navigable waterway routes, and other transportation segment data owned by Mn/DOT. The system is being developed to provide a central source of information on roadway locations that can be used throughout the department for integrating other spatial data on assets (such as signs and culverts) and for other data applications such as Mn/MODEL, the department's model for predicting archeological significance. The system will have the following characteristics:

- A stable method for determining location and attributes of data;
- New route naming and numbering methods for determining locations;
- A central "storefront" for the data and tools for easy display and editing of map and tabular data;
- Historical research capability and the ability to plot locations for future programmed/planned system additions; and
- Ability to convert various formats of data. For example, a management system manager could send a coordinate request and in return obtain county, city, township, Mn/DOT district or other geographic location information.

An innovative, iterative design approach was adopted for the LDM, wherein design, build, and test phases are carried out simultaneously. The LDM also uses a unique concept called Change Groups that allows several data owners to manipulate the model within a single session. For example, the mapping unit will first apply the geometry information after which the data group can add feature information. This will speed up the data exchange process.

The LDM will use the Mn/DOT's GIS base map to integrate data collected using various referencing systems. The 1:24,000 GIS base map has several layers such as transportation, boundaries, railroads, and navigable waters. The transportation layer contains all roads as separate feature classes, and data is assigned directly to anchor sections running from intersection to intersection. The intersections are called anchor points, made up of identifiable locations with unique x/y coordinates. The department continually calibrates and enhances the base map to ensure that it is current and accurate.

TIS will support a variety of planning and operations applications. For example, easy access to roadway inventory and traffic data will benefit statewide and district long-range performance-based planning, investment analysis, and project development activities. The integrated data will also support traffic studies; planning for traffic operations and snow removal operations; and the development of new applications for routing oversized and overweight vehicles. The new system can be used to summarize point event data in order to determine areas of high frequency (e.g., high-crash locations), perform event overlays (e.g., determine crashes that occurred on bridges), generate ad hoc reports from the available datasets, and create high-quality maps.

The Office of Transportation Data and Analysis has begun a data partnering exercise with local governments, inviting them to provide data in return for access to the LDM and the latest department crash and traffic data available in TIS.

Integrated Data Architecture

The TIS database is in Oracle and access to the data was developed using ESRI's ArcView. The LDM is currently designed with a JAVA-based graphical user interface. Because the intent was to develop a thin client application, Mn/DOT is working toward a web-based interface. For now, standard reports will be generated from the data and made available on the web for users to manipulate with a desktop tool. The LDM will be supported by a data warehouse that does not allow transactions but houses the various data sets and allow for data mining. To allow for maximum flexibility, the LDM is being built on a multi-tiered architecture.

Lessons Learned

Mn/DOT faced a number of challenges while developing the LDM: dealing with the unfamiliar concept of linear datum; an evolving technical architecture; a new object-oriented design process, limited experience of the project team; keeping the enthusiasm and momentum going for such a lengthy project; and overcoming office and division boundaries. The process of building a database system from a series of legacy systems is complex and is taking longer than originally expected. Mn/DOT is finding that users have high expectations with respect to the timing of results and the agency is working hard to communicate with users to establish expectations that are more realistic.

Mn/DOT has learned a great deal in the process. Many lessons are worth sharing with others, including:

- A phased approach including manageable increments with well-defined products is the most practical way to approach a data integration project;
- Frequent interaction between developers and users at all stages of development is critical;
- From an organizational standpoint, champions at the highest levels of the organization ensure a successful outcome; and
- The strong performance-based planning approach within the department set the stage and allowed continued support for this large project.

Future Plans

Mn/DOT plans to develop, document, and implement new business processes to support the LDM.

The LDM and other GIS applications support Asset Management for Mn/DOT by providing accurate location and description of assets. The data involved does not cover the entire set of transportation data. There also is no link to financial planning in the department. Mn/DOT will continue to work toward integrating other data systems with the LDM. For example, the right-of-way and utilities department is interested in exploring a connection. The LDM will provide a means to share data externally as cities and counties are encouraged to use the system to share data with the state.

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Acknowledgment

Information for this detailed review was compiled with the assistance of Jonette Kreideweis, Jim Muske, Dan Ross and Matt Koybol, Office of Transportation Data and Analysis, Minnesota DOT.

Montana DOT Performance Programming and Infrastructure Data Inventory

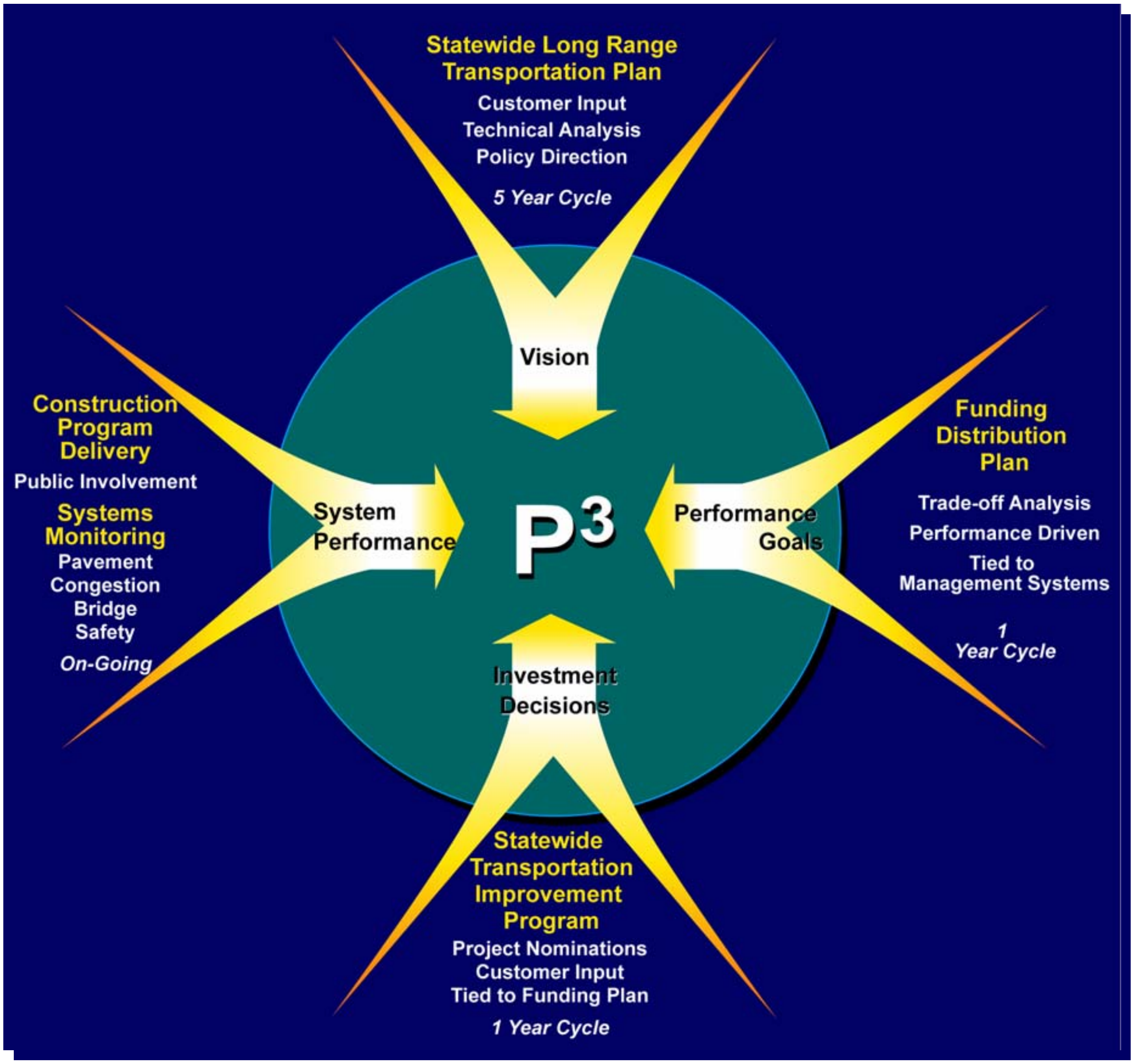
History/Background

The Montana Department of Transportation (MDT) uses a process called Performance Programming to make systemwide investment decisions and distribute agency resources. MDT defines the process as "a method to develop an optimal investment plan and measure progress in moving toward strategic transportation system goals." The Performance Programming Process includes the use of performance goals, measurement of system performance, and determination of investment decisions. Several management systems are used to summarize and view the condition of transportation assets and to predict system conditions at various funding levels. An iterative process is used to estimate the impacts of investment options on system performance. The management systems are used to analyze pavement condition, highway congestion, bridge conditions, and safety. This approach, while not called Asset Management within MDT, is a needs-based planning approach used to support resource allocation decisions. The result is a funding plan that is based on predicted system performance given anticipated funding and a specific program mix.

For several years, MDT has been perfecting the Performance Programming process that has been in use for the last four years. Prior to this, MDT allocated resources based on lane miles for National Highway System Routes. For other systems, state law controlled funding distributions. The Performance Programming approach is now used on the Interstate, non-Interstate NHS and State Primary and includes roughly 70 percent of the funds available in the capital program. This method is a new way of doing business at MDT that ensures accountability to the legislature and the public. Other benefits include a customer service driven system, support for sound investments, and the fact that it cuts across many facets of the organization.

Figure 1 illustrates the Performance Programming Process.

Figure 1. Montana's Performance Programming Process



Data integration has been a priority for MDT for several years. It did not occur as a result of the above-described Asset Management approach but had existed as an agency goal for a while. The existence of a good data integration approach within the agency ensures success of the Performance Planning Process. The agency is very aware of the importance of necessary data and tools to support inventories and resource allocation. Progress could not have been made in the Performance Programming Process if it had not been precede by linear referencing system and data integration efforts.

Integrated Data Considerations and Architecture

All management system data are housed in MDT's Oracle database. The management systems include:

- Maintenance (an in-house product is used);
- Pavement (system developed by Texas Transportation Institute (TTI));
- Bridge using Pontis;
- Congestion;
- Traffic Data;
- Roadlog; and
- Safety.

MDT uses ESRI software for many of its applications. A stable route-milepoint linear referencing system has been in place for several years. Through this system it is possible to combine the data in the management systems by viewing several layers of data at once. However since the data has not yet been fully integrated, in some cases, the data may not line up and may need to be verified (e.g., a bridge may not fall over water as shown on the basemap). MDT is in the process of collecting GPS data for public road in the state and database files are being generated for every road. The intent is for attribute data to be collected with a GPS Technology, so it can be located and referenced in terms of state plane coordinates.

To address data integration issues, MDT's Information Services Division is managing an Infrastructure Data Inventory and Needs project. This project is being coordinated with several divisions and a draft of the results will be available on June 30, 2003. MDT established an Information Technology (IT) Governance Committee made up of technical and policy subcommittees who will review the results and recommendations.

The project was needed for a variety of reasons, including:

- Each work unit has its own data quality control procedures;
- Inconsistent data definitions existed;
- No one was addressing the need to integrate data for decision-making;
- There was redundancy in data sources;
- There appeared to be a mismatch between the available data and use of the data by different program areas; and
- A common set of standards was desired for the entire agency.

The project was designed to address the following data integration issues:

- Cross-departmental concern that data could be collected more efficiently;
- Concern about quality of data;
- Limited department-wide data integration; and
- Proliferation of secondary data items.

The anticipated benefits of the project include:

- Improved data consistency, quality, accuracy and timeliness;
- Reduced redundancy of effort;
- Consolidation of data collection efforts;
- Cost avoidance through establishing efficient, integrated data collection and reporting systems;
- Establishment of a more efficient department-wide data management and administration procedures; and
- Improved customer service.

Several of the major outcomes include a data inventory, a data dictionary, and data administration policies.

Inventory of data items was accomplished through identification of cross-functional working groups to assist with this task. The groups consisted of members from the Divisions of Administration, Maintenance, Engineering, Motor Carrier, and Planning. Interviews were conducted to determine how data is collected, who uses it, how it is defined, what it is used for, how frequently it is or should be collected, and how often it needs to be updated.

A recommendation regarding the further development of the existing data dictionary or purchase of a comprehensive department-wide data dictionary for infrastructure information is the second major outcome. A data dictionary will assist in identifying duplication and conflicts in data, establish naming conventions, standardize data definitions, and assess the way data collection is accomplished as well as being a resource to identify and understand available data.

A Data Administration Policy based on the department-wide information technology governance structure are expected to be developed by a steering committee and adopted by the IT Governance Committee. This will include data collection, definitions, reporting practices and common exchange standards. Business and technical issues also will be addressed in the recommended policy.

Lessons Learned

One of the most significant organizational issues for MDT has been keeping its staff up to date with the changing technology. A solid training plan has been employed to resolve this issue.

The most significant data integration issue has been establishing and enforcing data management standards. MDT believes that the Infrastructure Data Inventory and Needs project will result in recommendations regarding the collaborative administration of data management within the agency to resolve this difficulty.

Future Plans

MDT has the capability of relating data stored with different location referencing methodologies. This technology is being "moved out" to all MDT computer systems. MDT does not want to be tied to a particular software package or technology. As such, they are moving towards Open Standards such as Scalable Vector Graphics (SVG) for GIS applications. MDT also will continue to examine and learn from data integration practices of other States.

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Acknowledgment

Information for this detailed review was compiled with the assistance of the following MDT staff:

- Ken Varnado, IT Manager – Information Services Division;
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- Bill Cloud, Data & Statistics Bureau Chief – Rail, Transit, and Planning Division.

New Mexico Intranet Decision and Analysis Support System

History/Background

The Transportation Planning Division of the New Mexico State Highway and Transportation Department (NMSHTD) is responsible for the collection and analysis of various data used to identify future roadway and budget needs. This data includes road network information, pavement condition, and accident statistics. All data are spatially related through a linear referencing system.

For many years, the Planning Division and the Information Technology Division of NMSHTD have been working to provide integrated data to their internal and external customers. The Intranet Decision and Analysis Support System (IDEAS) is being developed to achieve this goal. Once fully implemented, IDEAS will provide graphical, transparent access to legacy information while leveraging historical systems with minimal overhead on the client or server end. It is intended to bridge the data disconnect between the agency's Planning Office, districts, and engineering units. The GIS base map was established during the initial release of IDEAS and has been maintained since then. Additionally, the agency has been working toward converting legacy data housed in a mainframe Consolidated Highway Database (CHDB) to Oracle. NMSHTD also has a comprehensive electronic document management system using FileNet scanning and imaging software. This case study will examine these efforts together because the ultimate goal of providing integrated data to transportation customers will rely on all components.

IDEAS was first conceived in the late 1990s as a result of a Federal Railroad Administration requirement for improved data on rail crossings. New Mexico was required to provide data on 800 at-grade rail crossings. Each crossing was located using a GPS and seven photographs were taken at each location. The prototype IDEAS application was created using the ESRI MapObjects product. Foundation Consulting Group and ESRI provided consultant support during these early stages. This prototype was successful and well received within the department. However, due to staff reorganization and shifts in the emphasis of administration, the project was put on hold. The agency is currently recruiting staff to manage the continuation and completion of the IDEAS project.

Integrated Data Considerations

IDEAS will provide the graphical web-based interface to the department's databases through data queries of the different information systems. It will support the functions of the planning, design, maintenance, and engineering divisions at NMSHTD by integrating relational databases, strip maps, bridge inspection reports, design drawings, and correspondences. It will do so with little impact on existing workflows as it will feed off of available data sources. The result will be a framework with easy access to support multiple decision-making processes that will directly impact the success of Asset Management at NMSHTD.

The data to be integrated for the IDEAS project will include traffic, accident, pavement, bridge, pavement condition rating, HPMS, strip maps, county maps, road maps and project evaluation reports. Another system currently under development is the Road Features Inventory system, which was developed to build and manage maintenance assets (signs, culverts, guardrails, etc.). The same linear reference keys used in IDEAS will access this data. All data is owned by NMSHTD. It will access some databases (such as bridge data) directly, while other data will be supplied to users through IDEAS.

IDEAS will use the agency's Linear Referencing System (LRS) to tie all data back to the roadway network and the application itself will be an ESRI ArcIMS application.

■ Integrated Data Architecture

NMSHTD originally used the legacy mainframe database ADABAS to create the CHDB in the early 1990s. CHDB consolidates 28 stand-alone applications including the Highway Performance Monitoring System (HPMS), pavement condition rating, traffic and accident reporting. The data is referenced by posted route, direction, and mile point. The agency has been working towards converting CHDB to Oracle relational database to be accessed with ArcSDE applications. To date, the accident, traffic monitoring and pavement management databases have been converted from the mainframe.

The agency's Transportation Planning Division implemented GIS in 1994. It has been calibrated to the CHDB, allowing access to over 10 years of attribute data. The GIS base map provides coverage for the entire state system and identifies structures and rail crossings. It currently has limited distributed use outside the Planning office.

The CHDB and the GIS will feed IDEAS, which will operate as a portal to the various users. IDEAS also has a set of web-enabled applications as follows:

- HiRide – application for the prioritization of railroad crossings using GX database, CHDB crash and traffic data, and photos;
- Project Evaluation Reports;
- State Transportation Improvement Program (STIP);
- Traffic Volume Estimates/Capacity Analysis;
- Historical data, including strip maps, bridge inspection reports, county maps, and road maps;
- Pavement Management System reporting; and
- Road Features Inventory (maintenance).

Lessons Learned

The development of the CHDB superseded IDEAS and represents early attempts to consolidate data. An agencywide survey identified that was needed universally through the department. Some of the challenges faced while developing the CHDB include:

- Ensuring that the database could be accessed at the desktop;
- Making do with limited funding to support the effort;.
- Outside influences that required the addition of several layers of security protocol which lowered usability of the database; and
- Difficulties or perceived difficulties accessing CHDB.

IDEAS posed its own unique challenges. NMSHTD was using several standards such as Active Server Pages (ASP), Dynamic Hypertext Markup Language (DHTML), and Extensible Markup Language (XML). Moreover the agency switched between the use of in-house and consultant staff through development of the system.

The major lesson learned during the development of IDEAS concerned the way in which support was generated for the project. Early buy-in for IDEAS was accomplished by the prompt release of the prototype rail crossing application. The success of this application demonstrated the value of linking data to a graphical interface and generated enthusiasm within the department to link more data to this system.

Future Plans

NMSHTD plans to resurrect the IDEAS project by the end of 2003. This includes fully integrating access to document management systems for accident records (FileNet) and bridge inspections (PONTIS). As more data becomes available, it will be linked to the front end. It is hoped that a fully functioning system will be in place in 2004. Regarding CHDB, complete migration of all data to an Oracle data warehouse will occur simultaneously.

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■ Acknowledgment

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New York State DOT Program Support and Project Management System

History/Background

In 1997, the Commissioner of the New York State Department of Transportation appointed an Asset Management Task Force that prepared a blueprint for developing and implementing an Asset Management system. Because NYSDOT already had traditional infrastructure management systems in place (developed in response to the ISTEA legislation and continued after requirements were relaxed), NYSDOT has emphasized linkages across the "stovepipes" in their Asset Management efforts, with a focus on the capital program update process as the integrating mechanism. NYSDOT's program update process involves the use of goals and performance measures to shape program development for pavement, bridge, congestion/mobility and safety. Regions propose programs of projects to meet the performance targets. While project selection decisions are made primarily at the regional level, a central review process has been established to monitor regional compliance with established policy direction within each program area, and to look horizontally across all program areas in each region.

NYSDOT's program support system/project management information system (PSS/PMIS) is used to track candidate projects throughout their life cycle, balance alternate programs against funding sources, and perform "what-if" analyses to determine the financial impacts of different sets of projects. Current efforts are focused on developing a methodology and prototype Asset Management system that supports evaluation of tradeoffs across diverse types of projects based on a common performance measure (excess user costs).

While data integration has not been a focus of the Asset Management initiative per se, both the PSS/PMIS system and work in the GIS area have been important enabling technologies for the type of cross-asset analysis that has been pursued. Both of these efforts have been significant; the PSS/PMIS system implementation effort began in 1990, and efforts are still underway to refine the system and make full use of its capabilities. Work on improving the quality and utility of highway system GIS data has been ongoing over the past decade. Work also is currently underway to replace legacy mainframe-based systems for maintenance of highway and bridge information with new three-tier Oracle systems.

A series of statewide information technology (IT) initiatives led by the New York State Office For Technology (OFT) is providing improved communications infrastructure and centralized data management services in support of an ambitious e-commerce/e-government vision for the state. These, together with the development of a statewide ITS architecture (to meet TEA-21 National ITS Architecture conformity requirements) will provide a framework for future data integration efforts at the DOT.

Integrated Data Considerations

New York has developed individual management systems for pavement, bridge, congestion and mobility, and safety. These systems store condition/performance information and are used for needs forecasting, investment alternatives analysis, and project selection and program development. Information on needs and candidate projects is brought together through the program update process; both the PSS/PMIS and GIS serve as chief integrating tools. The PSS/PMIS provides project management, scheduling and tracking information, and can be used as a mechanism to look at projected and actual accomplishments and associated costs at the program level. PSS/PMIS integrates data previously stored in several isolated and often duplicative project management databases. GIS is used to integrate diverse data stored on the various "stovepipe" infrastructure management systems.

NYSDOT uses two linear referencing methods. A field-posted reference marker system is used for most of the highway maintenance, traffic, and accident data. A milepost system is used for inventory and capital project information. GIS route networks for dynamic segmentation have been constructed for each of these systems, using a common base map of highway centerlines. An ArcView extension was developed to produce a spatial overlay of the two systems, thus allowing users to integrate data using different linear referencing methods. The new integrated Asset Management system and the individual stovepipe management systems rely heavily on dynamically segmented data based on the enterprise linear referencing system(s) maintained by the GIS unit.

A high-level ITS data architecture was developed for NYSDOT by Jaffe Engineering and Development Industries and Ron Ice and Associates. Based on the national ITS architecture, it presents an integrated view (at the conceptual level) of a variety of data useful for real-time traffic management, some of which are related to Asset Management.

Each element of the data warehouse would have a variety of data services, including Federal reporting packages, data marts, on-line analysis and mining, virtual data warehouse services (to support information exchange), and traffic and roadside data archival services to collect data for use in planning, research, and analysis. Of primary interest for Asset Management are import of traffic volume and speed histories from roadway sensors into the master highway inventory database via the archived user data service. Of primary interest for traffic management are exports of highway maintenance work orders and traffic management plans for construction projects from transportation operating agencies. Note that this is a long-term vision, and most of the elements are yet to be designed and implemented.

Integrated Data Architecture

Data integration has not been an explicit objective of the Asset Management initiatives in NYSDOT. As noted above, the focus has been more on establishment of the core business processes and analysis tools and approaches for making cross-asset tradeoff decisions.

However, these efforts are clearly enabled by the existence of databases and GIS tools that can be used to obtain a consolidated view of asset conditions and needs at different geographic levels. Future efforts to migrate data from the mainframe to three-tier Oracle applications will facilitate development of automated interfaces across the various systems.

The key data sets and processes supporting Asset Management activities include:

- **Asset Inventories –** NYSDOT's core highway inventory, pavement condition and traffic count data reside in flat file databases on mainframes. A major effort to create a new three-tier Oracle Highway Data Management System (HDMS) containing highway inventory, pavement inspection, traffic monitoring, and HPMS information is currently underway (CGI Group is the vendor), and is scheduled to go into production in the fall of 2003. In addition, the mainframe-based DB2 bridge inventory and inspection data system is being converted to a three-tier Oracle database application (Keene is the vendor).

- **Management Systems –** The congestion (CNAM), pavement (PNAM) and bridge (BNAM) forecasting models are stand-alone PC-based applications. PNAM and BNAM were recently converted from Fortran to Visual Basic. CNAM is a Borland dBase application. These models serve functions similar to the Federal Highway Administration's Highway Economic Requirements System (HERS) and Bridge Investment Analysis System (BIAS). The safety management system is a three-tier Oracle application. Each of these systems is an information consumer from the asset inventories, feeding information on needs into the PSS/PMIS. Data transfer processes between asset inventories and the management systems are partially automated, as are transfer of needs and project data between the management systems and the PSS/PMIS. NYSDOT also is in the process of implementing a maintenance management system (MAMIS Booz-Allen Hamilton as the vendor) which will be used to schedule and track maintenance activities and their costs. This system will be a web-enabled, client-server-based system with an Oracle database.

- **PSS/PMIS –** This is an enterprise-wide client/mainframe system with a DB2 database.

- **TRANS*PORT –** This is the AASHTOWare system that provides for project construction cost estimating, bid letting management, and construction project management. The forecasting models receive their unit cost estimates for construction materials from TRANS*PORT.

Data integration activities in NYSDOT are guided by the broader set of statewide information technology initiatives led by OFT, established in 1997 to play a technology planning, policy-making, and coordination role and oversee development and operations of shared technology infrastructure components. Major OFT initiatives support establishment of a statewide e-government and include:

- Establishing a statewide data center that consolidates mainframe operations across state agencies;

- Incorporating the existing New York Geographic Information System Clearinghouse into the OFT's Center for Geographic Information, which facilitates geographic data integration and sharing. The Center provides centralized development, integration and maintenance of geographic data layers and on-line access to GIS functionality; and

- Implementing NYeNET, a high-bandwidth statewide electronic communications network. A contract has been recently awarded for development of a statewide wireless network, which will provide a common communications platform across agencies.

Lessons Learned

NYSDOT's Asset Management system development efforts have been guided by four basic precepts:

- Put the business foundation in place first. Asset Management systems must effectively support decision-making, so it is critical to define these decision-making processes prior to fully developing the support systems. NYSDOT has established the program update process as the business process within which key Asset Management tradeoffs are made.

- Focus efforts on assets that the agency wishes to include in tradeoff analysis, and on those for which data collection programs and stovepipe management systems are already in place. NYSDOT has selected pavement, bridges, safety, and mobility as the key types of investments to include in the integrated Asset Management system.

- Establish a common measure for comparing investment candidates. Excess user costs has been selected as this common measure, defined as the incremental costs incurred by users as a result of a facility in less than "ideal" operating conditions. Three cost components are considered: delay costs (for passengers and freight), accident costs, and vehicle operating costs.

- Use an economic evaluation method to compare candidate project proposals. NYSDOT has selected a benefit/cost analysis method for comparing investments. Benefits are defined as the decrease in excess user costs attributable to an investment.

NYSDOT faced a number of challenges in the course of developing its prototype Asset Management process:

- Development of agency costs for safety and mobility has proved difficult. Given that the choice of an appropriate treatment for a congested or high-accident location is less straightforward, development of agency costs for pavements and bridges has been relatively straightforward, since these can be derived from management systems that include treatment matrices relating condition levels to recommended repair actions, each of which has a unit cost.

- Determination of the "base" criteria or standards for the definition of excess user costs must be done with great care, since the tradeoff model is highly sensitive to the condition or performance level beyond which "excess" user costs are presumed to be incurred. NYSDOT has decided to make use of a panel of experts responsible for regional program development to assist in this area.
- It will be important to put the results of the tradeoff analysis in their proper context – i.e., they provide a network-level assessment of the relative merits of different types of investments. They are not intended to replace the types of analyses performed by the "silo" management systems, which can better address selection of appropriate treatments and life-cycle considerations.

Future Plans

NYSDOT will complete development of the three-tier applications for highway and bridge data. While not in the current scope of HDMS, the development of a highway data warehouse to serve a variety of applications is viewed as the next logical step. Following a successful prototyping effort, NYSDOT plans to proceed with full implementation of its computerized system for asset tradeoff analysis. Once the HDMS is completed, interfaces between the pavement, bridge, safety and congestion management systems will be adjusted to improve automation and increase efficiencies.

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Acknowledgment

Information for this detailed review was compiled with the assistance of Louis Adams and John Shufon, Planning and Strategy Group, New York State Department of Transportation.

Ohio DOT Data Warehouse and Base Transportation Reference System

History/Background

The vision of data integration at the Ohio Department of Transportation (ODOT) is to integrate legacy systems with a common referencing system in order to provide decision-makers and policy-makers with better information. In 1999, in support of this goal and to facilitate GIS deployment and decentralization, ODOT began its Base Transportation Referencing System (BTRS) initiative. At that time, available data were scattered throughout the agency in several legacy systems that used various referencing methods. The result of this effort was a set of referencing standards, methods to translate data in existing legacy systems to these standards, a data warehouse to store the integrated data, and a query and mapping tool to access the data.

The Division of Planning, Division of Information Technology (DoIT), and many other ODOT entities are responsible for maintaining and enhancing the BTRS. The Division of Planning's mission is to propose strategies that address transportation needs and goals in order to plan, build, and maintain safer, more efficient multimodal transportation systems in Ohio. A main goal of the BTRS is to provide quality information so that the planning mission at ODOT can be accomplished.

Integrated Data Considerations

BTRS began with the goal to integrate roadway, bridge, traffic, crash, and other data from 11 legacy management systems, namely:

- Automated Traffic Recording (ATR);
- Bridge Management System (BMS);
- Construction Management System (CMS);
- Culvert Inventory;
- Overweight Permitting;
- Highway Safety Program (HSP);
- Pavement Management System (PMS);
- Project Development Management System (PDMS), replaced by the Ellis project management system;
- Roadway Inventory (RI);
- Transportation Management System (TMS); and
- Weigh-in-Motion (WIM).

In addition, systems continue to be added using the new referencing standards. These standards enable integration with BTRS.

This data is accessed through a user-friendly interface. Current uses of the BTRS include developing multi-year district work plans, analyzing statewide highway volume-to-capacity ratios, congestion analysis, providing support for ODOT's pavement and bridge management functions, tracking pavement and bridge performance, generating straight-line diagrams, and responding to ad hoc data requests.

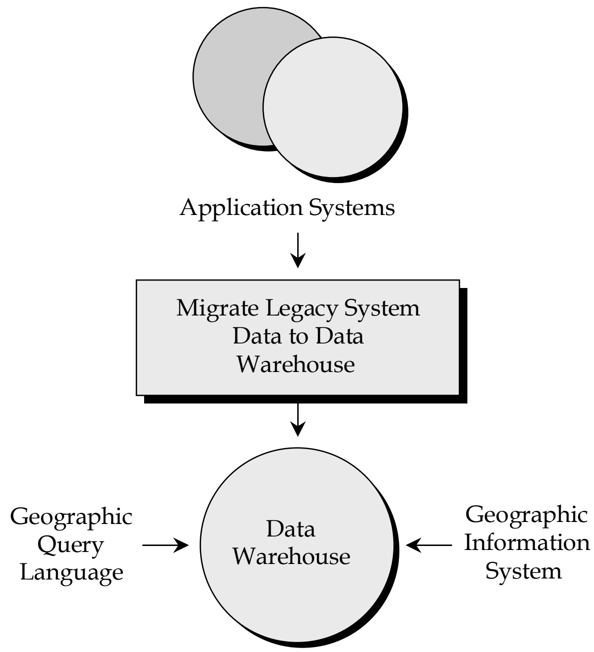
For example, in the area of pavement management, BTRS help ODOT staff chart and analyze existing Pavement Condition Rating (PCR) data, identify deficient roadway segments, group these segments into practical planning sections, prioritize planning sections based on the results of a pavement matrix, analyze future projected PCR based on funding alternatives, evaluate secondary results, and repeat the analysis as necessary to optimize results.

Data in ODOT's legacy systems are referenced using straight-line mile logs and other attributes such as jurisdiction, county, route, and logpoint. The data were integrated by creating a record every 0.01 mile in each database, and using lookup tables to calculate a latitude and longitude for each of these log points. These tables were analyzed to identify records that did not match BTRS standards. Legacy system owners performed extensive data scrubbing routines to improve the quality of the source data. This "brute force" approach ensured that data inadequacies were not perpetuated in the new system.

Integrated Data Architecture

Integrated data is stored in a Sybase IQ data warehouse as illustrated in Figure 1. BTRS standards and a GIS environment enable data from any legacy database to be linked to any other database. The system is designed so that data is available to each information system and can be queried and analyzed by either the Department's SQL tool, Hummingbird's Graphical Query Language (GQL), or GIS (Geomedia). Enterprise data is updated daily to insure that users are working with the very latest data available.

Figure 1. BTRS Data Warehouse



Lessons Learned

The biggest technical challenge of the BTRS project was developing a data warehouse because the quality of legacy data varied greatly and numerous referencing methods were in use. In response to these challenges, ODOT focused on a common referencing system, developed procedures to translate data to this system, and worked with system owners to scrub their data. Additional technical challenges resulted from the decision to use Sybase – the department's enterprise database management system. ODOT found that major GIS vendors did not always provide sufficient support for Sybase.

Another hurdle was the prevalence of proprietary views of legacy systems and datasets. Project staff addressed this issue by creating a cross-disciplinary steering committee of system owners charged with recommending policies and standards throughout the project.

Additional factors that were critical to the success of ODOT's data integration efforts included a well-defined implementation plan, executive support (director and assistant directors), and a system that provides easy, seamless access to current enterprise data, some of which are locally collected and maintained.

Future Plans

ODOT's future goals are documented in its *Vision 2006* report. The agency recognizes it must be more results-oriented and customer-focused. It identifies seven guiding management principles, including understanding the transportation system and needs and accurately predicting where the system will be in 10 years. Each year ODOT adopts a set of strategic initiatives that support this vision. These initiatives include:

- Adopting clear goals to improve freeway pavements;
- Developing a strategy for measuring and managing congestion;
- Improving performance indicators to measure personnel and process improvements; and
- Adopting a sufficiency rating to measure the performance of highways and analyze trends. (This rating will be based on pavement condition, bridge condition, traffic volume, and accident rates.)

Through its integrated data, analysis capabilities, and reporting tools, ODOT's data warehouse and BTRS support the agency's efforts to develop realistic views of current and future network performance and communicate this information to decision-makers and policy-makers.

Specific BTRS-related plans include adding data from more systems to the data warehouse, training staff on how to access the data, developing new systems that comply with the newly developed referencing standards (e.g., signal inventory, maintenance quality system, sign inventory, and passing/no passing inventory), customizing GIS tools, and a marketing effort that will facilitate further integration of the system into the agency's culture.

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Acknowledgment

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Pennsylvania DOT Integrated Information Systems

History/Background

The Pennsylvania Department of Transportation (PennDOT) Asset Management Concept Plan, published in 2001, recommended improvements to information systems supporting Asset Management as a priority initiative. These enhancements are needed to improve information on asset inventory, condition and needs throughout the organization, in support of both operational management and capital planning activities.

The Concept Plan recommended that Asset Management requirements be clearly articulated and incorporated appropriately into information technology (IT) planning, and that an overall architecture be defined for how different systems and databases will work together to address Asset Management requirements. This architecture would address integration of information across systems, and incorporate existing and planned systems, as well as new (not-yet-identified) systems as needed to best address the requirements. A high-level system architecture was proposed as a starting point, shown in Figure 1.

Key systems in Figure 1, including the Roadway (Pavement) Management System (RMS), Bridge Management System (BMS) and the Maintenance Operations Reporting Information System (MORIS) are based on old, outdated technology and no longer meet the needs of the user community. A number of current and proposed initiatives involving these systems have the potential to dramatically improve information integration and analysis capabilities in support of Asset Management. These initiatives include:

- Reengineering of the maintenance management system (MMS);
- Identification of key players for a centralized data management committee;
- Acquisition of an ERP/SAP suite of financial management tools to replace the existing Financial Management System (FMIS);
- Sign Inventory Management and Ordering System (SIMOS) that integrates 11 sign management systems;
- Completion of a comprehensive five-year GIS Strategic Plan and Implementation Project; and
- Rewrite of the bridge management system (BMS).

Integrated Data Considerations

Ownership of the data required to support PennDOT's Asset Management functions is split between the Bureau of Planning and Research, the Bureau of Maintenance and Operations, the Bureau of Highway Safety and Traffic Engineering, the Bureau of Design, and the Program Center. Although some of these data items are integrated, PennDOT does not have a methodology in place to share data with all potential users. The agency plans to enhance the integration of this data by redesigning its legacy systems.

The Bridge Quality Assurance Division of PennDOT's Bureau of Design is currently working on this project by reengineering select components of its bridge management processes. The DOT's bridge management processes consist of planning, program management, maintenance and preservation, and project monitoring. However, the reengineering effort focused only three of these processes: bridge planning, programming, and maintenance.

Figure 2 summarizes the proposed functionality of PennDOT's BMS. Expected benefits of the rewrite include:

- Enhanced integration of the BMS with other department management systems, such as the RMS, MORIS, the Multimodal Project Management System (MPMS), the Engineering Construction Management System (ECMS), the video log system, the enterprise data warehouse, the Electronic Document Management System (EDMS), and the geographic information system (GIS);
- Improved planning and programming tools for partners through shared BMS data and common analysis tools;
- Support for statewide Asset Management initiatives and GASB 34 compliance;
- Support for electronic collection of bridge inspection data; and
- Ease in collecting, maintaining, editing, and accessing bridge-related data, including electronic documents such as photographs, drawings, inspection reports, etc.

Figure 3 indicates current and proposed interfaces between the BMS and other PennDOT management systems. Further integration with other management systems is expected to result in the following benefits:

- Integration of the Maintenance Management subsystem with MORIS will synchronize the systems and eliminate duplicate entry of data;
- Integration of the Cost Estimating subsystem with MPMS and ECMS will help update cost factors used in estimation;
- Integration of the Structure Planning subsystem with MPMS and ECMS will enable automatic updating of milestones and project numbers related to a structure;

- Integration of the Structure Planning subsystem with MORIS will enable the user to view past maintenance work done on the structure;

- Integration of the Reporting subsystem with other management systems will allow access to multiple databases while generating reports; and

- Integration of the Structure Planning subsystem with the Automated Permit Routing/ Analysis System (APRAS) will allow access to current structure information during the permitting process.

Figure 1. PennDOT High-Level System Architecture Concept

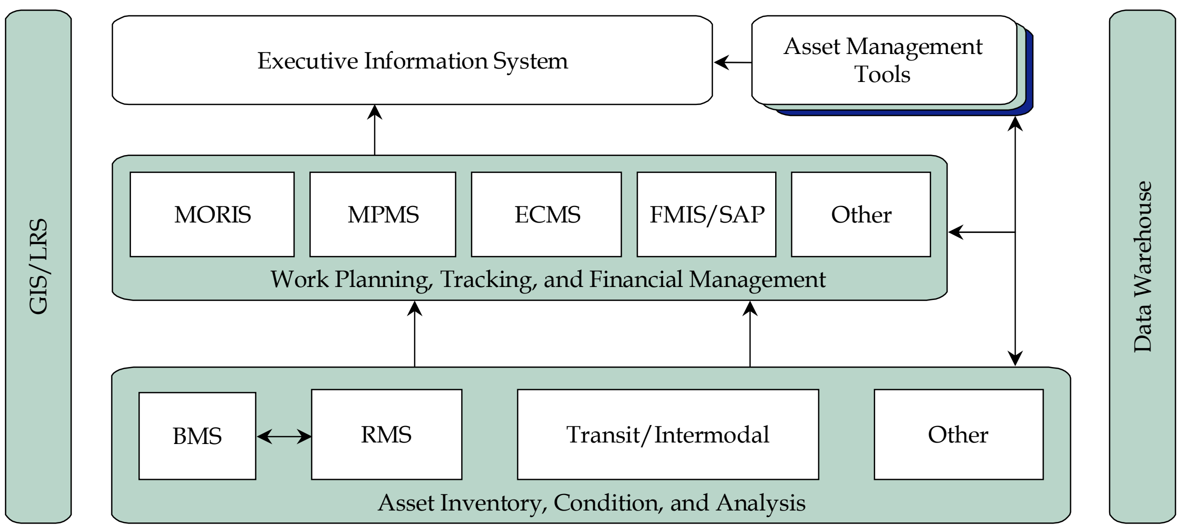
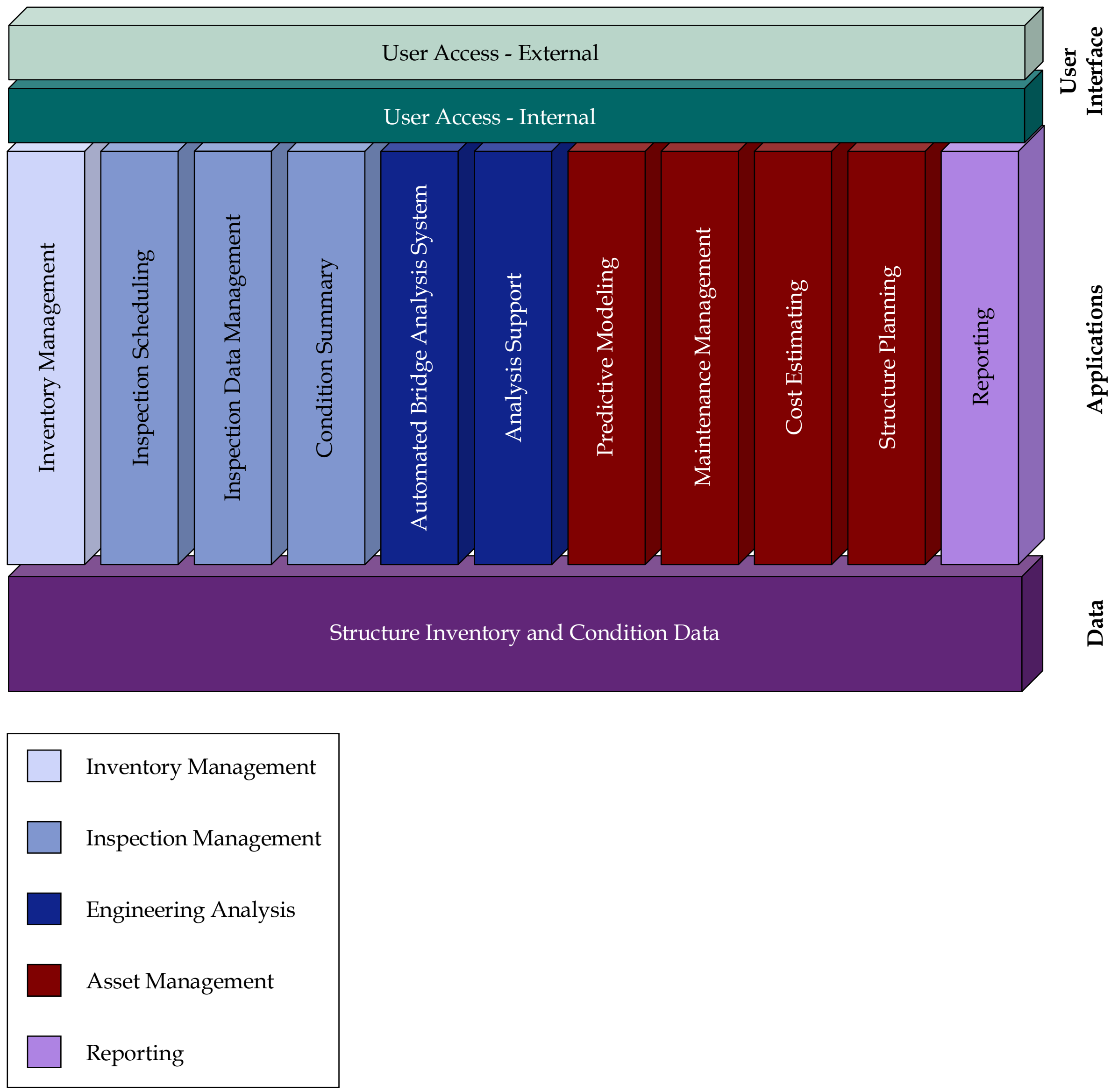


Figure 2. BMS Subsystem Model



■ Integrated Data Architecture

PennDOT has developed a GIS that integrates data from the RMS, BMS, TIMS, HPMS, MORIS, MPMS, SIMOS, and the Accident Records System (ARS)/Crash Reporting System (CRS) into an Oracle database. Data is extracted from these systems using a series of custom-developed data extraction and update routines. The data is then normalized in order to reduce redundancy.

The Geographic Information Division (GID) has developed a series of client-server applications and thin-client web applications that enable users to access, query, and analyze the integrated data. For example the Interactive Straight Line Environment "ISLE" and VideoLog applications enable users to view multiple roadway attributes simultaneously as they "drive" along a RMS segment. These segments are roughly one-half-mile long and are defined by county-route-segment-offset. A Data Dictionary Application also is available online to help users understand what data is available.

Lessons Learned

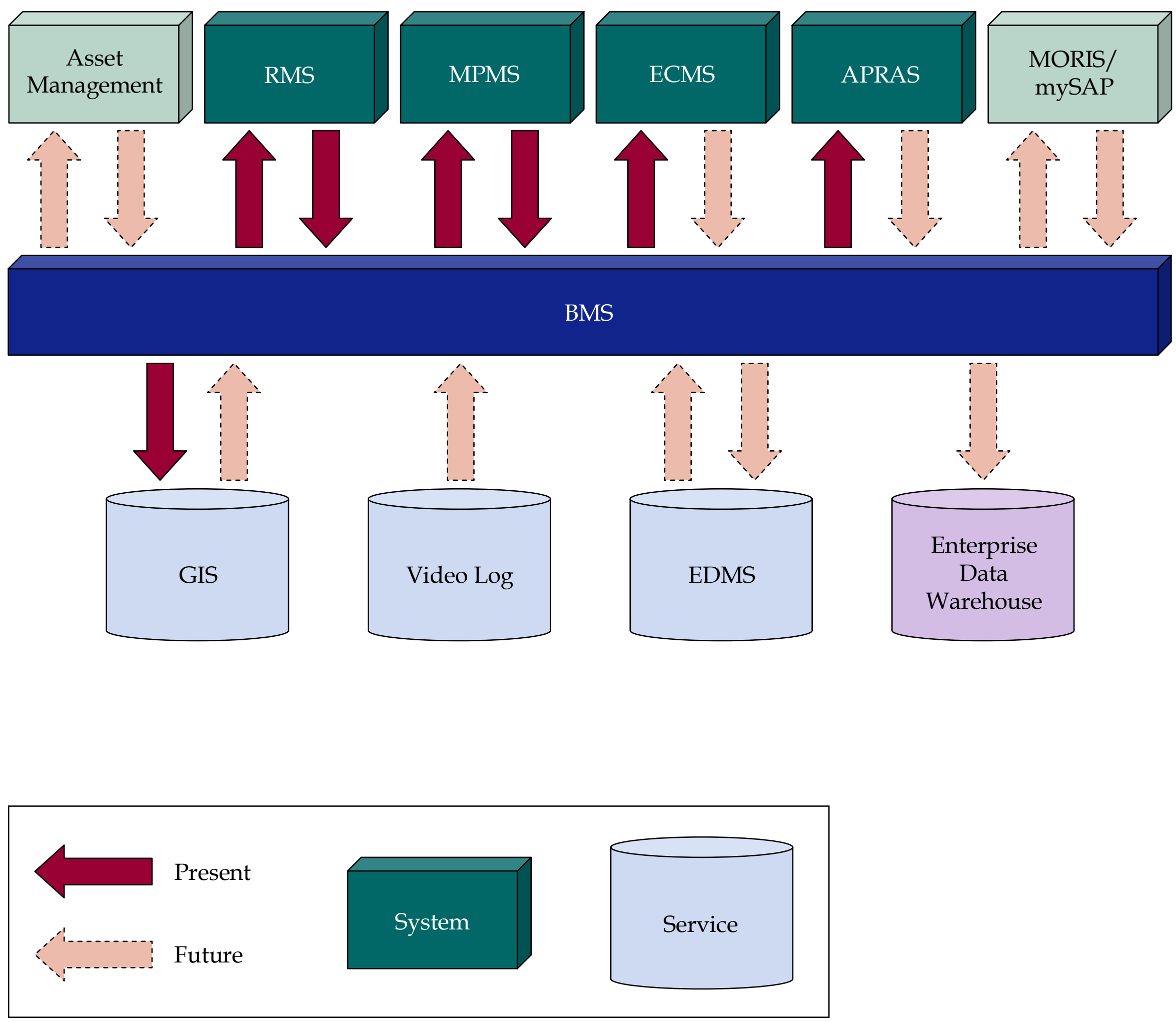
The implementation of PennDOT's GIS Strategic Plan spanned several years and addressed a wide range of IT issues. Critical success factors for this effort included:

- Adherence to and periodic review of the strategic plan;
- Development of a GIS plan that focuses on the problems but that does not constrain the solutions;
- Utilization of strong project management methods;
- Development of contractor relationships that promoted training and technology transfer;
- Emphasis on outreach and public relations efforts;
- Project objectives that included keeping up with latest technology advancements as they became available;
- Documentation on the data structure and available applications in order to facilitate use and understanding of the system by data customers; and
- A balance between strategic planning, practical applications, and future maintenance and operations requirements.

PennDOT began the rewrite of its BMS after completing the Asset Management Concept Plan and bridge process reengineering effort. The rewrite is currently in progress, so it is too early to fully evaluate this approach to system enhancement. However, several preliminary observations can be made. For example, the Asset Management Concept Plan provided the context for the new BMS, particularly with respect to the need for network-level analyses and the DOT's enhanced capital-programming processes, and helped ensure that the new BMS will be consistent with the agency's overall vision of Asset Management. Several benefits of the reengineering effort also have been identified, including:

- The effort helped PennDOT identify new opportunities for rapid implementation (e.g., the development of a network planning tool based on existing tools);
- It helped limited the scope of the software development process because the BMS is being designed to support only those areas of the business process addressed in the reengineering effort;
- It established a common vision for the new BMS across the agency; and
- It enabled creative technological solutions because the reengineering effort emphasized bridge business processes at the beginning of the process rather than potential IT tools.

Figure 3. BMS Interfaces with Other Management Systems



Future Plans

In an effort to continue enhancing the data required to support Asset Management, PennDOT has identified the following initiatives:

- Reengineering the Roadway Management System (RMS);
- Developing an Enterprise Data Model (EDM) and incorporating it into a comprehensive data management strategic plan;
- Developing a (location) referencing management system; and
- Integrating data from additional systems into its GIS database.

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Acknowledgment

Information for this detailed review was compiled with the assistance of Hal Rogers and Mike Long from Pennsylvania DOT.

South Carolina DOT Integrated Transportation Management System

History/Background

The South Carolina Department of Transportation (SCDOT) currently does not have an Asset Management plan nor a legislation mandating one. However, the Department has a strong interest in the concept of Asset Management evident by the creation of an Asset Management Program Manager in 1998. This manager is responsible for managing all assets in SCDOT and for ensuring that other members of management within the agency have the most current information upon which to base decisions pertaining to the efficient use of agency resources. The Asset Management Program Manager has been tasked with creating an Asset Management Implementation plan and is responsible for generating the Annual Accountability Report, which documents the agency's success in meeting its key strategic goals related to safety, improvement, operation, and management of the transportation system. The position works very closely with the Applications Manager in the Information Technology (IT) office to develop necessary tools and programs to manage data pertaining to the assets.

SCDOT has the fourth largest state highway system in the nation, yet they have the fifth lowest state gas tax. Growing tourist and freight movements in destinations such as Charleston and Myrtle Beach have put a strain on the transportation system. As a result, an accelerated construction program was put in place a few years ago to meet the growing demand. Around the same time, the need for Asset Management was identified within the agency to track the condition of physical assets and ensure efficient allocation of limited capacity enhancement and operations resources.

SCDOT understands that a critical component of a successful Asset Management process is efficiency in data retrieval from a variety of agency databases. Data integration is a component of the Asset Management Implementation plan currently under development.

Integrated Data Considerations

SCDOT also is planning an Integrated Transportation Management System. This system will allow users to geographically obtain information on system conditions and construction projects. The assets to be viewed include fixed (geographically identified) and mobile assets. One of the data systems, the Roadway Information Management System (RIMS), was acquired from Tennessee (see Tennessee detailed study describing TRIMS). RIMS was adopted in SC where they enhanced the system to include safety and traffic information. Other systems include the Pavement Evaluation system, Road Inventory system, Highway Management system, and the Preconstruction Planning Management system. These data are currently housed in Oracle, Atabase and Sequel databases.

Each of the management systems has a different method of referencing this data. For example, pavement data is recorded every half a mile, road inventory data is based on milepoints and segments, and the construction data is based on milepoints within the project limits. Dynamic segmentation is used to reconcile the differences in linear referencing systems.

Integrated Data Architecture

The need for exchanging data across different databases is being accomplished with Microsoft BizTalk server. This product is designed to allow integration of enterprise applications. It allows SCDOT to access a variety of databases so they can effectively "talk to one another." The server is capable of receiving data in various formats, saving this original data, and then converting it into a predetermined format to be distributed to users through an interface designed to meet their individual needs.

This process is currently being tested for a half-mile segment as a "proof of concept" within the agency. It is currently being presented to upper management for approval and application to the entire state highway system. The project is managed by an IT Application Manager, who approves all application development efforts. This guarantees consistency of future management systems and promotes integration of data.

Lessons Learned

The biggest challenge facing SCDOT in developing an Asset Management Plan and integrating database systems is getting everyone involved and making them buy in on the benefits of organizing data within the agency.

The Asset Management Program Manager is faced with the challenge of coordinating a variety of management systems throughout different offices. The key has been to ensure that data integration is being accomplished without sacrificing the needs of the individual offices. For example, the road inventory system has to report Highway Performance Monitoring System (HPMS) data and address the need for data sharing. The Annual Accountability Report helps the Department get buy-in on the agency goals. For this report, all program managers meet annually to discuss performance results for their areas according to the Malcolm Baldridge quality system. This method ensures common understanding of agency goals including the need to integrate data to manage assets.

SCDOT has learned to plan systems carefully and recommends that other agencies not simply add technology or get carried away by the latest gadgets. Patience is critical as according to the Asset Management Program Manager "none of this happens overnight."[2]

Critical to the success of the Asset Management program for SCDOT is the ability to maintain ITMS themselves. They do not want to rely on generic products or technology that may soon be obsolete.

Future Plans

Two additional existing systems will be integrated with ITMS: Site Manager (construction bidding and contracting systems) and the financial accounting system. The BizTalk data integrator server will continue to be used.

The entire state-maintained road system will be inventoried using GPS and the information will stored in the ITMS. Within this integrated system there will be an ability to toggle between linear (route-milepoint) and coordinate referencing systems.

SCDOT has been and will be heavily involved in national Asset Management initiatives including conferences and research panels. They will look into best practice Asset Management data integration and will try to draw from data integration experiences of other agencies.

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Acknowledgment

Information for this detailed review was compiled with the assistance of the following South Carolina DOT staff: Carl Chase, Transportation Assets Manager and Doug Harper, Application Development Manager, Information Technology Service.

[2] Interview with Carl Chase, South Carolina DOT, June 11, 2003.

Tennessee DOT Roadway Information Management System

History/Background

A major data integration effort at the Tennessee Department of Transportation (TNDOT) is the Tennessee Roadway Information Management System (TRIMS). First developed in 1973, TRIMS was TNDOT's first computerized information system, designed as a main-frame system to store roadway data. Since that time, it has evolved into an enterprise-wide, GIS-based, web-enabled, client/server application accessed by over 800 staff from across the agency.

In the mid 1990s, a comprehensive TRIMS upgrade was initiated in order to address several shortcomings of the original system:

- The system contained only roadway data;
- Users could not produce maps based on the data in the system;
- Access to the data was limited throughout the agency because the system was housed within one section;
- Data sharing was limited to hard copies of reports;
- Data access was limited to a predefined set of queries; and
- The system was not GIS compatible.

The Traffic Statistics Section and Safety Planning Section operate within TN DOT's Planning Division. These sections are responsible for maintaining TRIMS, training users, and generating reports. The Mapping and Inventory Section, which also is within the Planning Division, is responsible for collecting inventory data used in the system and for maintaining its GIS spatial network.

Integrated Data Considerations

TRIMS contains various data on more than 87,000 miles of roadway, including roadway inventories, road condition, bridge condition, crash statistics, traffic data, rail-highway grade crossing data, and project data. The system integrates data from relational databases, high-resolution photolog data stored on Terrabyte servers, digital plans, and scanned documents.

TRIMS is used daily to support planning, traffic, engineering, maintenance, and safety functions. For example, maintenance personnel use the system to maintain an inventory of highway features (e.g., guardrails, signposts, no passing zones, wildflower plots, sections requiring extra paint striping, etc.). GPS data enables planners to identify sections of highway with dangerous curves or steep grades. Engineers use the materials module to correlate highway segments with low skid numbers with the mix materials and material suppliers used for the segments. TRIMS' Bridge Inspector's Module enables regional staff to directly update inspection records and record maintenance activities. The system also enables users to access pavement reports and supports Highway Performance Monitoring System (HPMS) and GASB Statement 34 reporting.

All TRIMS data is geographically referenced using a county-route log-mile point system. A key feature of the database design is its dynamic segmentation capability, which enables users to readily link data from multiple tables. For example, users can define a beginning and end point along a roadway and query-specific locations. Users can query TRIMS data by zooming on a particular location on a map, or conversely by generating a map based on tabular data.

A popular feature of the system enables staff to select a section of roadway to "drive through" by view pavement conditions and safety features based on digital photos taken from a van-mounted camera every 100th of a mile.

Integrated Data Architecture

A team of consultants worked with TNDOT to develop and implement a flexible and efficient architecture for TRIMS. It consists of a single Oracle Spatial database with links to distributed attribute tables. LRSx, a linear referencing system module extension to Oracle Spatial, is used to maintain the spatial relationships to these tables. Changes in road alignments, for example, will update the linear measures in the attribute tables. Conversely, modifications to the date in the distributed tables can be synchronized with road geometry stored in Oracle Spatial. Existing data collection workflows were continued in order to keep maintenance responsibilities as close to the data source as possible. The database contains descriptions of external tables, data fields, and joins the criteria. For example, TRIMS users can access pavement reports based on data from the PMS FoxPro database. The database routines that enable this access are transparent to the end user. The warehouse supports both state and DOT standard GIS applications. In addition, users can access TRIMS data using an intuitive map-based web application. Query results can then be exported to Microsoft Office applications.

Lessons Learned

TRIMS has fundamentally changed the way TNDOT conducts business because it provides easy, widespread access to current mission-critical information. As a result, agency staff are able to make more informed and timely decisions.

TRIMS components were implemented incrementally (including a roadway inventory database, reporting capabilities, GIS, and web enabling). This approach focused the project team on one set of technical challenges at a time. The result was that the effort was easier to manage, risks were reduced, and a quicker return on investment was achieved.

Future Plans

TNDOT is in the process adding a new automated inventory process to the data maintenance and route modification system in TRIMS. Data files and GPS will come directly from the field inventory for uploading by the mapping section and direct input into the TRIMS automated inventory process. This will greatly streamline the updating process. TNDOT also has improved its GASB 34 report processing with the capability of accurately reporting additions, changes and deletions for route modifications due to inventory changes, functional classification changes, and structure changes.

Looking ahead, TNDOT will comply with GASB Statement 34 requirements using the modified approach. This approach requires reporting current system condition, establishing a target condition, and estimating the funds required to achieve the target. As its s infrastructure management processes evolve in response to these requirements, the agency will continue to leverage the data integration capabilities of TRIMS (e.g., automated generation of GASB 34 reports).

In addition, several specific system enhancements have been identified, including links to additional systems (e.g., Project Programming and Resource Management System, Construction Management System, and a new Maintenance Management System), tailoring commercial off-the-shelf (COTS) software to support data integration, duplicating photolog data in regional offices to improve ease of access to the data; and developing a truck routing application. Since TRIMS becomes more complicated to use with each additional feature, there are future plans to streamline the system's most popular features.

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Acknowledgment

Information for this detailed review was compiled with the assistance of Paul Boyd, Information Systems Manager 1, Tennessee DOT.

Utah DOT Asset Inventory and Analysis System

History/Background

The Utah Department of Transportation's (UDOT) asset management efforts focused initially on developing an asset management system for a 17-mile stretch of reconstructed Interstate 15 (I-15) in Salt Lake City. That initiative has enabled UDOT to perform preliminary tests on asset management concepts and evaluate their value before ultimately implementing a statewide management approach.

UDOT's present asset management approach, which was recently adopted through an executive director-level policy statement, involves cross-asset tradeoff analysis, condition versus budget forecasting, and performance-based resource allocation. UDOT is in the process of implementing a business-wide approach to asset management utilizing all of the state network pavement and bridge data.

The I-15 project established four main objectives pertaining to the information technology (IT) aspect of UDOT's asset management implementation efforts, namely:

- Provide the tools needed to collect condition and inventory data pertaining to the highway assets;
- Provide the ability to view and analyze this data to assess needs and future conditions;
- Make the best possible use of available systems and IT resources, a more economical approach than one that relies solely on new system development; and
- Establish a framework that would enable UDOT to implement a strategic asset management system which would integrate the entire department, by systematically automating and integrate individual parts of the planning and operational processes one step at a time – "Keep it simple. Keep it growing. Keep it Utah's."

In order to meet these objectives UDOT plans to use existing systems for collecting inventory and condition data, incorporating additional asset classes and more detailed data to the existing systems as needed, and implementing dTIMS™ CT, an asset inventory and analysis software, for integrating asset data and performing cross-asset analysis.

Integrated Data Considerations

UDOT's existing suite of management systems provides many of the components necessary for applying transportation asset management concepts. Key examples include:

- Pavement Management System (PMS) – UDOT uses dROAD and dTIMS from Deighton Associates Limited for pavement management. dROAD stores pavement data, and dTIMS is an analysis tool that uses the pavement data stored in dROAD. UDOT also employs two additional systems to support pavement management: a DOS system for pavement data collection, and an ADABAS/Natural mainframe system as its official repository of Highway Performance Monitoring System (HPMS) data.

- Bridge Management System (BMS) – UDOT recently implemented the current version of the Pontis BMS, Version 4.0, in an Oracle database, and is using the database to perform queries and analyses of its structures.

- Maintenance Management System (MMS) – UDOT's suite of maintenance management tools includes an MMS, a Maintenance Management Quality Assurance (MMQA) software, and a Maintenance Features Inventory System. Together these systems represent the state-of-the-practice in terms of analytical approaches to maintenance management.

UDOT will continue to use these management systems to support day-to-day operations. Additionally, the integrated data in dTIMS CT will be used to support network-level strategic decisions, such as policy development and long-range planning. For example, it is anticipated that senior leaders in UDOT's Transportation Systems Management Team (TRANSMAT) will use the system to come up with network-level policy decisions. Users of this system will be able to view current inventory and condition information as well as future conditions resulting from different budget levels for different assets.

GIS Linear Referencing

UDOT uses GIS in conjunction with a number of its systems for summarizing query results on maps and performing spatial analyses. GIS tools licensed by UDOT include ESRI's ArcView® 8.1, ArcInfo™ 3.2 and ArcIMS™ 3.0. These tools are used most frequently in conjunction with data from dROAD and Pontis, and accident data. A major challenge in using GIS at UDOT is in *contending* with the differences between linear referencing systems used by UDOT systems. The most common referencing systems used at UDOT include:

- Reference Post – Referencing is based on mile posts physically located on the roadway; and

- Accumulated Mileage – Referencing is based on the mileage measured from the beginning of the route, which may or may not match the mile posts along the roadway.

Even when two management systems use the same basic method, there may still be differences in the route numbering, direction reference, or underlying network upon which the systems are based. Consequently, the agency has identified 26 different linear referencing systems currently in use.

UDOT recently adopted a standard LRS that will serve as the basis for integrating data. Legacy databases will be updated so that the core attributes required for this LRS can be added. In the end, the legacy systems may continue to operate with their existing referencing method, but data from the systems will also be tied to the standard LRS.

Integrated Data Architecture

UDOT recently adopted dTIMS CT as a repository for asset inventory and condition data. Other data that needs to be integrated will remain in UDOT's existing management systems. It is envisioned that these data will be downloaded to the dTIMS CT database with a series of automated interfaces. Data stored in dTIMS CT will be updated periodically using a process that is easy to follow and does not involve manual manipulation of the source data.

Once all data is stored in dTIMS CT, UDOT will use the system to perform "what-if" analyses and to allocate resources across assets. Users will be able to access the results using the dTIMS CT interface through a series of canned views and reports.

Lessons Learned

A key lesson that UDOT has learned over the course of its data integration effort is that organizational decisions (e.g., amount of resources available for IT tools, the details of the asset management business processes that will be implemented, etc.) should be finalized before any IT work begins. Conducting these activities simultaneously can lead to significant changes in direction and/or rework of the data integration initiatives.

At the beginning of the initiative, it was difficult for UDOT staff to find sufficient information on IT alternatives to meet their needs. In hindsight, they feel they could have taken a different approach. They could have first thoroughly defined all business objectives and documented them in a request for information (RFI). They could have then used the RFI to solicit ideas and information on potential solutions from private vendors.

A significant management systems requirement identified by UDOT is an emphasis on identifying, locating, and characterizing the condition and performance of specific assets. Adding asset identification fields to both existing and new systems will address this need.

Future Plans

UDOT recently created a position for Asset Manager. The Asset Manager is responsible for the organizational, business process, and IT components of UDOT's asset management efforts. The Asset Manager is working with UDOT's TRANSMAT to define organizational roles and responsibilities with respect to asset management, finalize an asset management framework, and fully implement dTIMS CT.

In terms of data integration, UDOT is focusing initially on integrating pavement and bridge data into dTIMS CT because these two assets represent the majority of its transportation investments. Additional data (e.g., safety, traffic, guardrail, etc.) will eventually be added. UDOT also recently started an effort to develop data update procedures and an approach for cross-asset condition versus budget forecasting.

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Acknowledgment

Information for this detailed review was compiled with the assistance of Neal Christensen, Utah DOT Director of Administrative Services; and Michelle Verucchi, Utah DOT Software Manager.

Vermont Agency of Transportation Integrated Asset Management System

■ History/Background

In 2001, the General Assembly of the State of Vermont passed Act No. 488 which, among other things, calls for a systematic, performance-driven approach to operating, maintaining, and upgrading all classes of assets. In response to this legislation, the Vermont Agency of Transportation (VTrans) developed an Asset Management Vision and Work Plan. As part of this effort, VTrans' current polices, business practices, and information technology environment were evaluated based on two benchmarks: 1) the state-of-the practice Asset Management as defined in NCHRP 20-24(11) Asset Management Guidance for Transportation Agencies, and 2) the requirements set forth in the Act. The Plan identifies several key asset management elements currently in place at VTrans and recommends a work plan for further improvement.

The VTrans Asset Management Vision states the following:

> "Transportation asset management at VTrans is a strategic approach to managing transportation infrastructure. It enables VTrans to improve how it conducts its business, how it reaches decisions, and how it leverages available data and IT capabilities. Asset management establishes common linkages between VTrans' asset classes in planning, program development, and program delivery."

VTrans anticipates the following outcomes and benefits from developing a comprehensive asset management system:

- Enhanced planning, programming, and budgeting guidelines that will align investment decisions throughout VTrans with agency policies and focus areas, resulting in increased quality of services;
- Reports identifying: 1) current and accurate asset inventory information in terms of effective performance measures; 2) target levels for asset condition compared to actual condition; and 3) estimated funds to maintain the target condition compared to actual costs. These reports will result in improved accountability;
- Standardized and ad hoc management system and GIS reports required to support planning, programming, and budgeting decisions, increasing credibility and making those decisions defensible;
- Analytical methodologies and tools to analyze the life-cycle costs and benefits of capital and maintenance projects, and to evaluate projects across modes and programs, resulting in increased cost-effectiveness;

- Suite of IT tools that generate strategic information across asset types that is consistent with tactical information, thereby enhancing vertical integration; and

- A set of department-wide organizing principles for existing and planned initiatives, resulting in improved horizontal alignment.

After completion of the Asset Management Vision and Work Plan, the state assembly required VTrans (through Section 33 of Act 141 of 2002) to establish an Asset Management Working Group, and to incorporate asset management principles into the ongoing performance measurement effort. The VTrans Asset Management Working Group was formed in September 2002 and has since been meeting regularly. The group is working to achieve a common understanding of asset management among key players at the agency, and has been looking at alternate approaches to developing an integrated asset management system. A Performance Measures Committee has been coordinating with the Asset Management Working Group to establish a set of performance measures to use for the overall asset management system.

Integrated Data Considerations

VTrans has separate databases and applications supporting different asset classes:

- The dTIMS pavement management system is in active use for storing and maintaining pavement inspection information, predicting future deterioration, recommending appropriate treatments, and conducting investment versus performance analysis. An effort is currently underway to update the performance models in this system based on statistical analysis of historical information.

- The Pontis bridge management system is being implemented. VTrans collects element-level bridge inspection data and keeps an up-to-date Pontis database. The system is being used to analyze current and future system performance.

- A maintenance management system is in place which tracks quantities of maintainable elements (e.g., culverts), as well as activities and their costs.

VTrans also has a pavement management system for airport pavements, a facility management system, and a vehicle/equipment management system. VTrans uses the preconstruction project management system Artemis and the AASHTO Transport construction management systems to plan and monitor construction work. The agency also has applications for maintaining Highway Performance Monitoring System (HPMS) data, traffic monitoring data, and crash information.

Linear Referencing

VTrans uses linear referencing to provide a common linkage across data used in the individual management systems and databases. It maintains two linear referencing systems

(LRS) – a town-based LRS that defines routes and sets the mileage along the route to zero at each town; and an end-to-end LRS that defines routes with continuous mileage. Most of the agency's data is referenced using the town-based system.

The Agency maintains a set of standard GIS coverages showing data of common interest. Updates to these coverages are performed on a periodic, as-needed basis.

A current project to automate the process of producing route logs will significantly improve integrated access to disparate data sources. This effort has involved developing a GIS-based repository of information on the state highway system. Route logs are maps of short (roughly eight-mile) sections showing a variety of roadway attributes (curves, grades, functional class, roadway and traveled way width, base and subbase thickness and materials, Annual Average Daily Traffic (AADT), crash data, bridge locations, etc.). Two separate applications are being developed – one focused on production mapping and the other a web-based application that will allow users throughout the agency to view route logs for selected locations.

The route log project is not explicitly part of the agency's Asset Management activities. However, it is bringing a variety of data together and will allow for mapping and queries using information across multiple asset classes and sources. The exercise in developing this data repository has been a valuable catalyst for increasing awareness of the need to view data as a shared corporate resource.

■ Integrated Data Architecture

GIS has been used as the primary data integration tool within VTrans. VTrans uses an SQL Server as its primary GIS data repository for highway information, though this data is pulled from a variety of sources, including Microsoft Access tables, spreadsheet files, and Oracle tables. The Vermont Center for Geographic Information maintains the master highway route system in ArcInfo. ESRI's ArcGIS tools are used to overlay different coverages and perform dynamic segmentation. Because VTrans is a relatively small agency, it has been able to rely on ad hoc processes for periodically updating the GIS data repository from various sources.

The maintenance management system data is also stored in a separate SQL Server database. Maintenance activity data can be integrated into the GIS data repository as needed.

An SQL Server data warehouse has been in place for a number of years to provide access to financial and project-status information on mainframe-based systems. This data warehouse also includes sign inventory information.

VTrans does not have a corporate data model, but is taking an initial step in this area to develop a metadata website that will contain an accessible inventory of all data elements in a variety of systems.

Lessons Learned

VTrans faces the following challenges in developing an integrated Asset Management system:

- Attaining a common understanding of asset management among the different units within the department. However, the Asset Management Working Committee has provided a useful forum for sharing of information about the different management system efforts and discussion of integrated approaches.

- Obtaining agreement on a set of performance measures that are useful at different levels of the organization, and for different purposes – e.g., budgeting versus day-to-day management.

- Fully integrating the use of management system information into decision-making processes.

- Integrating data from different sources and making it available in a useful form for decision-makers throughout the agency. There are both technical and organizational challenges to making this happen, including:

  – Integrating data that has coordinate-based geographic referencing (e.g., crash data with GPS coordinates) with linearly referenced data;

  – Integrating project history data that is structured to support financial tracking rather than spatial analysis. For example, a single project may include work in multiple locations;

  – Integrating data pertaining to facilities that are not on the state system – the LRS only covers the state highway system;

  – Maintaining acceptable standards of data quality and currency, and ensuring that the units responsible for each data source understand the needs of others in the agency;

  – Time-consuming intermediate processing steps required to pull data that is maintained in legacy systems into a central repository;

  – Redundant and inconsistent data in multiple systems; and

  – Updating linear referencing as a result of facility changes such as re-alignments, allowing for location-based trend analysis while maintaining the integrity of historical data.

■ Future Plans

VTrans wants to achieve an understanding of asset management throughout the agency, and move towards performance-based planning, programming and budgeting. Integration of data and analysis capabilities across different asset classes is viewed as a key element of realizing these objectives.

One of the initiatives recommended in the VTrans' Asset Management Work Plan is the development of a comprehensive IT strategy. This effort would define the data and analytical capabilities required at all levels of the agency to support asset management practices. The final product of this initiative would be an IT strategic plan that ensures these needs are met in the most effective possible way. The plan would focus on maximizing the use of VTrans' current data and analytical capabilities. The work plan defines the scope of this effort as follows:

- Document the current overall planning, programming, and budget processes at VTrans, and the types of information and analysis used in these processes;
- Develop a set of "use case" scenarios for how these processes would be assisted by additional data or computerized tools;
- Review current and planned databases to identify gaps, areas of improvement, and opportunities for integration;
- Compile a list of data and analysis requirements and identify which requirements are not currently addressed by current or planned systems;
- Establish a consistent set of requirements for all asset management systems so that their results can be consolidated (e.g., inventory listings, condition summaries, comparison of conditions to targets, listing of proposed projects by location, type and status, estimates of funds required to meet condition targets, mix of preventive maintenance versus major rehabilitation/replacements, and LRS requirements);
- Reinforce existing GIS and data warehouse efforts by documenting their criticality for asset management implementation as platforms for data integration; and
- Build a formal logical data model and system architecture to support asset management needs in a comprehensive fashion.

Rather than undertaking a major effort to develop this comprehensive IT strategy at this point in time, VTrans is taking some initial steps in the short term to move towards development of an integrated Asset Management system, including learning about commercially available systems. At the same time, its GIS and Information Systems groups are continuing to make progress in data integration that will support the agency's asset management objectives.

VTrans plans to establish a new GIS/data group with representation from all units that collect or produce location-based data. This group will meet quarterly to ensure that updates to linear referencing are implemented consistently across data sources.

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Acknowledgment

Information for this detailed review was obtained from the following VTrans staff: Shawn Nailor, Automated Services; Jonathon Croft, Mapping and GIS Services, and Bart Selle, Automated Services.

Virginia DOT Enterprise GIS Database

■ History/Background

Data integration in Virginia Department of Transportation has followed two complimentary but somewhat independent paths:

1. Development of an agencywide or enterprise GIS that can integrate spatial data with business data and provide input to other spatially enabled information systems; and

2. Development of the Asset Management Program, which will integrate both legacy and new asset data as well as utilize enterprise spatial data. The Inventory and Condition Assessment System (ICAS) project was one of the projects initiated to support the Asset Management Program.

Geographic Information System

VDOT's vision for developing an enterprise GIS was established in 1997-1998. The agency's strategic plan called for an enterprise approach to support future spatially enabled applications. VDOT also determined that no single vendor's product could meet all the requirements without major customization. However, as the project evolved, the scope changed somewhat to implement a commercial off-the-shelf (COTS) GIS and Oracle relational database management system (RDBMS) solution. After evaluation, ESRI's ArcSDE/ArcIMS/Oracle solution was selected. VDOT began to staff its GIS Program to oversee development, testing, and production of this system.

VDOT's goal was to link the business data to the spatial data using linear referencing as one of the location keys, as well as to provide spatial data sets to business users. Accomplishing this would enable the traditional information to be served to VDOT users in a graphic map format. It also would provide a single point of access for enterprise spatial data for fat and thin clients, and standardize spatial parameters (e.g., LRS) to simplify the integration of various spatial data sets.

More specific objectives included developing an Internet map server for query and display of maps through VDOT's intranet browsers; creating application program interfaces (API) accessible by popular programming languages and GIS scripts; integrating VDOT's multiple LRS on a common transportation reference frame; and providing on-line help to make the system more user friendly.

The plan was to phase in the system components as the technology matured, especially the web-GIS services. Therefore some of the requirements were forward-looking, including on-the-fly location referencing system conversions for disparate data, an information locator with strong metadata content, custom thin client interfaces, and linkage to real-time information such as ITS data.

The enterprise system was intended foremost to serve internal VDOT users, and used specifically as a GIS data repository. Today it serves as a model for similar web-based projects in other VDOT business units, such as Asset Management and CEDARS (Comprehensive Environmental Data and Reporting System). Eventually, the enterprise GIS will allow access to the public through the Internet, with facilities for a customer information system and interagency data sharing.

Asset Management

VDOT began to look at Asset Management in 1995 to address a number of critical issues. At that time, VDOT did not have a complete picture of the state's transportation infrastructure and its condition. Consequently, the agency was unsure that it was making the best possible investments, was unable to evaluate the results of strategies and investment, and was in a weak position to advocate policies and plans. The 1995 review concluded that VDOT needed to re-engineer its business processes to:

- Produce a comprehensive inventory;
- Make best investment strategies;
- Manage assets throughout the life cycle rather than by stage;
- Optimize over all assets and asset life-cycle maintenance;
- Develop a consistent service delivery statewide; and
- Quantify the infrastructure.

The outcome of the review was the creation of the Inventory Condition and Assessment System (ICAS). ICAS was designed to address the above deficiencies and provide:

- Comprehensive inventory – all assets (pavements, bridges, drainage, roadside, traffic);
- How many, where, what condition;
- Data for business decision support system; and
- Basis for Asset Management.

Thus, ICAS became the primary mechanism for the collection and assimilation of asset data in VDOT. The first step was to create an infrastructure inventory to provide asset-based data recording. This would enable resource investments to be attributed to assets – financial, equipment, and human. At the same time, ICAS was designed to support work planning, work implementation and the evaluation of results. For example, for the first time assets would be managed through the entire life cycle from planning and alternatives evaluation, through design, construction and maintenance prior to retirement, after which the cycle begins again. Similarly, managing the use of the asset was introduced, which could potentially bring a more integrated approach for managing information such as land use permits, hauling permits, routing traffic flow, capacity, impact, trip, and travel analysis.

The ICAS name has now been replaced by the more generic term Asset Management.

Integration Between GIS and Asset Management

The evolution of the enterprise GIS architecture and Asset Management systems in VDOT has continued to converge on adapting the software components as follows:

- Web-GIS services employing ArcSDE and ArcIMS;
- Thin clients with browsers rather than GIS clients;
- Integration of data via distributed databases rather than a central data repository;
- Support for business applications and integration of business data via LRS either through Highways by Exor or by external procedures in the GIS;
- Collection of spatial and attribute data using GPS to improve the positional accuracy of centerlines and business data; and
- GIS developing to support new business activities such as ITS and 511 Weather Services.

VDOT intends to implement the new architecture and Asset Management business processes incrementally, subject to budget and other resources available. To test the methods and technologies the agency has undertaken pilot projects in three counties – rural, urban, mixed rural/urban – and has fine-tuned these for application through the rest of the state. The aim is to build a platform for future development that is robust enough to accommodate the needs of current and future users.

Integrated Data Considerations

From the outset, there were a number of critical data issues needed attention. Firstly, it was necessary to identify what data was available to work with. Secondly, evaluating data quality, especially data in legacy systems, the absence of data standards, and the multiple location referencing methods, presented a number of challenges. Thirdly, data was formatted in different projection systems and data formats that required a significant preprocessing effort. Fourthly, the volume of data for 60,000 miles of roads for the entire state is huge. To give one example, the aerial photographs alone consume 1.2 terabytes of storage.

With respect to data layers, a schema was developed that grouped layers by roads, imagery, jurisdictional boundaries and water bodies, and business data (e.g., traffic counts, accidents, inventory data). The roads layers were built on the Inventory Condition and Assessment System (ICAS) centerlines employing ESRI's measured shapefiles format, which support linear measurement. The roads layer included planned roads defined in the Six-Year Improvement Program. The business data was spatially indexed using LRS methods, which entailed some clean-up to improve the location accuracy. As part of the enterprise GIS development, it was intended to include the County Map centerlines, which would be conflated to the ICAS Centerlines. At the same time the current LRS would be updated where appropriate. The right-of-way imagery would be updated when available. More linkages to business data (stored in the data warehouse) were planned, together with the addition of other environmental data such as soils, wetlands, and topography.

The linear referencing system is the foundation for the location of VDOT's asset data. LRS was chosen as the method to accomplish integration because of its ability to:

- Define location in space and on the network (i.e., spatial referencing);
- Define connectivity of assets to the network, and of parts of the network to itself (i.e., establish topology); and
- Define temporal versions of the spatial and attribute data to support planning scenario evaluations.

Location, connectivity and time will be addressed in the data model. For the ICAS project, VDOT adopted the standards and methods recommended in the NCHRP 20-27 Project on Linear Referencing Systems implementation. The Highways by Exor program was selected for the ICAS project in part because it meets the requirements of the NCHRP 20-27 data model, and was therefore able to perform the linear data management and temporal data management required by ICAS. VDOT has since settled upon an implementation of the ESRI transportation data model known as UNETRANS, which incorporates elements of the NCHRP 20-27, but also includes a good deal of flexibility in the data model including temporal data versioning, which lessens the need for a proprietary program such as Highways by Exor.

Integrated Data Architecture

VDOT faced a number of critical design issues. The business needs identified more than 200 concurrent users over a wide area network, and over two terabytes of imagery. Consequently, the system requirements specified a large number of hard drives on data servers, massive data backup, high bandwidth, and significant performance tuning.

The solution was to separate the business/spatial data from the image data. The system configuration includes two data servers, one for the image data and one for the business/spatial data, and one application server for ArcIMS. The data servers also host the GIS software (ArcSDE) and Oracle DBMS. Both sets of servers use Windows 2000 as the operating system.

The architecture is expected to evolve as the technology changes. Specifically, it will incorporate new COTS functionality as it becomes available, for example the further development of web-based services. The primary goal is to continue to support application needs of VDOT business units, and provide a common architecture upon which other business units can build their GIS. The ESRI Geography Network will serve as a model for systems integration.

Lessons Learned

The model of integration with location, connectivity and time as central components proved to be far more difficult to implement than originally thought. It is necessary to communicate the concept early and often so as to achieve buy-in from users as well as set expectations realistically. It is easy to underestimate the importance of human and organizational issues, especially when they impact established business processes.

VDOT continues to utilize Highways by Exor, but in a more limited role than originally envisioned. VDOT has learned that it is important to:

- Choose the software based on the data model;
- Understand the data model;
- Define business requirements and rules in relationship to the data model;
- Start with the smallest possible asset data sets; and
- Prototype business requirements and push them through the system.

The Asset Management life cycle is a big project with many dimensions. VDOT's attempt to standardize the process through a COTS product was only partly successful. Even so, the process of discovering how to implement Highways by Exor provided some valuable lessons in determining the most appropriate role for the off-the-shelf solution vis-à-vis other custom solutions. Given the broad range of Asset Management activities in a DOT it is difficult for any one product to provide a comprehensive solution.

Future Plans

VDOT has learned not to rely on a single vendor solution, but to pursue open standards as much as possible. The agency is interested in implementing standards that may emerge from the National Spatial Data Infrastructure Framework Project with respect to the transportation data layer, and in coordinating with the I-95 Corridor Coalition regarding a regional multi-state transportation network, at least for the interstate and state routes. VDOT is embracing web-based services, and view Internet map servers as an integral part of its enterprise architecture. In the future, it sees more services being accessed remotely via the Internet; including data uploads from local PDAs, as well as the ability to query data and applications in the field, perhaps via wireless communications. The rapid changes in technology require a flexible open-systems approach. VDOT is conscious of the need to take small steps to take advantage of these improvements within the context of enterprise architecture.

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Acknowledgment

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Washington State DOT Transportation Framework for GIS

History/Background

One of the Washington State Department of Transportation's (WSDOT) data integration efforts is the development of a State Transportation Framework for GIS called WA-Trans. The objectives of WA-Trans are to:

- Identify and recruit partners to develop and maintain a GIS layer of multimodal transportation data;
- Develop a data model and establish standards for the framework;
- Establish institutional arrangements to facilitate data collection and dissemination; and
- Implement software and processes to support integration of new data, data maintenance, and data access by partners and the general public.

The current WA-Trans effort began in 2001. A key first step in the process was the creation of a steering committee. This committee consisted of representatives from a wide range of Federal, state, and local agencies. In addition, a larger stakeholders group was formed to facilitate buy-in and collect feedback from potential internal and external users.

Project staff recently completed an in-depth examination of the technical aspects of the system. During this process, several specific businesses needs were identified and prioritized, and the data items required to meet each need were documented. Next steps include identifying existing data sources and developing the scope for the first of a series of pilot studies.

Integrated Data Considerations

Several agency functions have been identified through the needs assessment process that will benefit from implementation of the WA-Trans, including planning, environmental analysis, inventory tracking for infrastructure maintenance, emergency management and response, transit operations, freight mobility planning and management, cross-governmental communication, and public communication.

To support these functions, WA-Trans will integrate GIS source material (e.g., existing road linework, imagery, digital line graphs, etc.) and project data from state, Federal, local, and private organizations. The details of this integration have not yet been finalized, but one option identified is to adopt a seamless base file such as Modernized Topologically Integrated Geographic Encoding and Referencing (TIGER) files or Geographic Data Technology (GDT) files. Anchor points could be added, and segments could be defined and related to the TIGER or GDT shape file. State attribute/inventory database records and system shape files could then be related to the segments. This process could be repeated with data from other organizations

Integrated Data Architecture

WSDOT has not yet decided on an architecture for WA-Trans. These issues will be resolved in the upcoming pilot studies. Conceptually, one alternative being discussed is a bundled approach to data integration, in which data would be collected from a variety of local, state, Federal, and tribal sources and combined into a centerline map. The data would go through a QA/QC process and be stored in a central clearinghouse.

The project team also is developing technical standards and protocols for data interchange. Exchange standards adopted by the American National Standards Institute (ANSI) and the conceptual data model developed by the U.S. Bureau of Transportation Statistics have been identified for further investigation.

Lessons Learned

WA-Trans is not the agency's first attempt to develop a statewide GIS framework. Previous efforts, which focused heavily on technical issues of the framework, stalled out. A key difference between the current project and past efforts is the detailed needs analysis conducted at the onset of the project. An exhaustive review of business needs was conducted before any technical work began. This approach enabled staff to clearly communicate the benefits of the system and attract an extensive group of committed partners. As more and more partners have come onboard, momentum for the project has grown. This momentum will be an important factor as project staff attempt to secure project funding.

Efforts to secure project funds also will be influenced by the results of the risk assessment. The WA-Trans *Risk Assessment* identifies 28 organizational and technical risks associated with this effort and provides the following information for each: consequences, impact rating (ranging from negligible to catastrophic), risk exposure level (none to high), probability rating (impossible to frequent), the phase(s) of the project to which the risk applies, and a mitigation strategy.

WA-Trans has benefited from the expertise of project partners. For example, through the DOT's partnership with Pierce County, a web site was created in order to support the needs assessment process. This site contains a list of business needs, identifies the data items required to address each, and enables project staff to track information on each data item (potential sources, accuracy requirements, etc.). After the needs were documented, steering committee members used the web site to evaluate and rank each need on a scale from one to five. These responses were used to identify the highest priority needs for consideration during the upcoming pilot study. This process was necessary because the initial list of business leads was too large to be effectively addressed simultaneously.

Future Plans

Development and implementation of WA-Trans is scheduled to proceed through a series of pilot studies. As the effort progresses, project staff continue to view the project in the context of WSDOT's overall business practices and corporate initiatives. For example, the framework will be consistent with the enterprise data model now being developed. For example, WA-Trans could potentially help maintenance staff integrate regional GPS data that is currently being collected and stored in isolation. The list of potential applications of the GIS framework will continue to grow as WSDOT places a higher and higher value on the data required to operate efficiently and effectively. This represents a fundamental cultural shift for an organization that has historically been solely project-focused.

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Acknowledgment

Information for this detailed review was compiled with the assistance of Tami Griffin, Transportation Framework Coordinator/Project Manager, Washington State Department of Transportation.

Local Agencies

Columbia, Missouri Infrastructure Management System

History/Background

The City of Columbia is mid-Missouri's largest city. It has a population of roughly 84,000 residents and is responsible for 381 miles of streets. In the early 1990s, the city's Street Division purchased a basic pavement management system (PMS) from the University of Kansas Transportation Center. The functionality of the system was limited, but prompted the division to develop a complete street inventory. In 1994, the Street Division implemented an off-the-shelf Asset Management system provided by Hansen Information Technologies, and populated it with data from its PMS database. In 1998, it upgraded to the Hansen Infrastructure Management System, Version 7.5 (now 7.6).

Columbia's Asset Management system meets the requirements established by GASB-34 for the modified approach to infrastructure valuation reporting. The modified approach requires an agency to manage its infrastructure assets using a system that:

- Maintains a current inventory of eligible assets;
- Maintains current asset condition data based on periodic, replicable field surveys; and
- Estimates the annual funds required to maintain and preserve the assets at or above a specified target condition level.

Integrated Data Considerations

Data in Columbia's Asset Management system includes:

- An inventory of 3,400 street segments, bridges, traffic signals, pavement markings, sidewalks, and storm water facilities;
- Asset location information based on X, Y, and Z coordinates;
- Condition data for street segments based on the Wisconsin Transportation Information Center's Pavement Surface Evaluation and Rating (PASER) system;
- Equipment, vehicle, parts/materials, contractor, and employee information;
- Work order information (location, date, activity, personnel, materials, equipment usage, etc.);

- Customer call logs; and
- Information for over 8,000 scheduled maintenance activities (surveys, crack sealing, sweeping, striping, mowing, etc.).

The system can be used by approximately 15 staff for asset maintenance planning, scheduling and budgeting. The system contains all information required for the Division to prepare and justify annual budget requests.

The Asset Management system can predict pavement performance based on historic records and specifications developed by the city's engineering department. Models that are more complex have not yet been necessary because Columbia's streets are in relatively good condition and requested funds have always been available.

The system also provides easy access to asset information and supports ad hoc queries.

Integrated Data Architecture

The software is Hansen Version 7.6, operating on a dedicated SQL Server for infrastructure management. This architecture gives the city the option to expand its asset data, provides quick responses to system queries, and is compatible with GIS add-ons.

Lessons Learned

Since implementing its Asset Management system, the street division has lowered its maintenance costs, improved pavement conditions, and reduced staffing resources required to document and justify its programs. From 1993, (a year before the first Asset Management system was first implemented) to 2000, the division reduced its maintenance expenses by an estimated 32 percent. This represents an annual savings of roughly $1.3 million over a period in which the city grew by more than 25 percent. A number of factors allowed the division to reduce its expenses:

- The automatic scheduling of preventive maintenance activities has reduced the department's need to "fight fires." Improved planning has reduced employee call-outs and unexpected overtime.
- Accurate cost records enabled the department to make sound in-house versus outsourcing decisions.
- Reports enabled supervisors to analyze work order costs.

Implementation of the Hansen system also has decreased the city's liability for personal and property damages. Accurate records ensure better defense when claims arise.

The major challenges faced in system implementation were assembling the asset inventory, developing new data codes that were consistent with existing terminology, and helping employees adjust to new operating procedures. In addition, the Street Department found it difficult to justify the initial expenses of the system. An understanding that the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 would eventually tie an agency's funding to its implementation of management systems helped support the Department's initial requests. Subsequent funding requests have been backed by the division's ability to quantify the financial benefits of its efforts.

■ Future Plans

The Street Division plans to integrate GIS functions with the Asset Management system. These enhancements will rely on the three-dimensional coordinates already stored in the system for inventory items. The department also plans to add other assets into the system and to expand its deterioration and costs models to deal with increasing budget pressures.

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■ Acknowledgment

Information for this case study was compiled with the assistance of Jim McKinnon, Street Superintendent, City of Columbia, Missouri.

New York City Transit Integrated Maintenance Management System

History/Background

Metropolitan Transportation Authority (MTA) New York City Transit (NYCT) is responsible for one of the world's most complex and extensive public transportation systems. Every day more than six million customers ride the agency's buses and subways throughout the five boroughs. NYCT's data integration efforts span a wide range of initiatives, including:

- Periodic updates of its enterprise office information system (OIS). This includes updating the agency's critical success factors, reviewing key business processes throughout the agency, evaluating previous information technology (IT) decisions, identifying specific systems initiatives, and considering the costs and benefits of IT options (e.g., business processes to support, architecture options, software and hardware standards, and organizational and staffing issues).

- Participation in the MTA's integrated GIS initiative. The MTA developed a web-enabled application to integrate data from its operating agencies into a GIS data repository.

- Participation in the New York State DOT's Integrated Incident Management System (IIMS) project. The objective of this effort is to improve coordination and data sharing by incident managers in various agencies

- Development and phased implementation of a coordinated Intelligent Transportation System (ITS) program. This program consists of a series of ITS projects that focus on providing customers with real-time information and improving the agency's fleet management functions.

- Development of an Integrated Maintenance Management System (IMMS). This effort is discussed in more detail throughout this review.

NYCT's Division of Car Equipment is responsible for the maintenance of nearly six thousand subway cars. In a joint effort with the agency's Division of Information Services, the Division of Car Equipment initiated the IMMS project to develop and implement a single software system that would address all of its information needs and support all of its business functions. Until that time, multiple systems had been developed to support individual maintenance functions. This uncoordinated approach resulted in the proliferation of inconsistent reports, redundant data collection efforts, and general inefficiencies in the division's operations and communications activities.

Integrated Data Considerations

In a yearlong planning phase, the project team interviewed 100 Car Equipment staff to document business practices and identify information needs. The team identified several business functions that the new system would support (e.g., inspection, budgeting, maintenance and repair, planning, human resource management, material management, etc.).

Once these functions were identified, the project team documented the relationships and work flow between them. Preliminary needs were validated midway through the process through a series of seven workshops in which more than 50 staff participated. Next, the project team identified 58 entities (i.e., items for which data was required) and identified the relationships between functions and entities. Within each function, staff can create, use, update, or delete an entity's data items. The final step of the needs assessment phase was to present the relationships between data items in an entity relationship diagram (ERD). The ERD illustrated business constraints and rules and was used by senior management to support their strategic business planning efforts.

Based on the findings of the needs assessment process, eight data sources (four internal and four external) where identified for integration into a single system that would support all of the division's business functions.

Lessons Learned

Since the IMMS project cut across a complex business organization and affected several very different business functions, the project team was faced with several organizational hurdles. For example, at the beginning of the process it became clear that staff from different parts of the division had different names and different definitions for the same data items. This issue was addressed through the development of a project glossary that defined each data item.

Secondly, system needs were mapped to business functions rather than the organizational structure. This approach provided stability to the project because the functions would not change unless the core business of the division changed. In contrast, the organizational structure of the agency changed four times over the course of the project.

It has been estimated that the full implementation of the IMMS saved the agency $22.5 million annually. Car Equipment also realized several additional intangible benefits, such as more informed decisions, faster access to information, and more efficient business operations.

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Puget Sound Regional Council Enterprise Data Model

History/Background

As the Metropolitan Planning Agency (MPO) for the Puget Sound region in Washington State, Puget Sound Regional Council (PSRC) is required to maintain a regional database of transportation and planning data to support its mandates. Attempts have been made to create data sharing standards and procedures with the member governments and Washington State Department of Transportation, but these are informal arrangements and do not constitute an agencywide standard. Attempts to standardize data integration have met with resistance because of the variety of information technologies in use in the cities, counties, and PSRC. Some members are reluctant to ratify a protocol that is imposed rather than reached by consensus. As a consequence PSRC has been edging forward in implementing informal bilateral agreements with its members and external agencies, while at the same time beginning a program to create an enterprise regional database for internal users within PSRC.

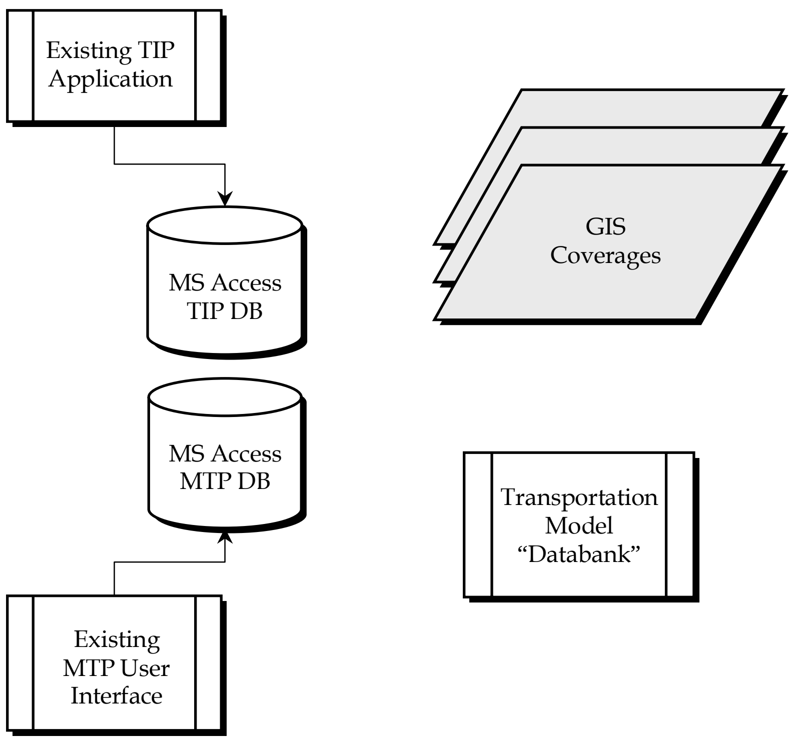
The focus of the data integration efforts is in two areas:

1. Integrating spatial data so that changes in members' geographic data sets can be more easily assimilated into the PSRC base map and GIS coverages. The PSRC digital centerline file to which transportation attribute data is referenced is named "Roads 97." In support of this objective, PSRC is a partner in Washington Department of Transportation's (WSDOT) Transportation Framework project, which is a partnership to create a feature identification standard in Washington (described in the WSDOT detailed review). This mirrors the GeoSpatial One-Stop initiative being implemented in the Federal government, both of which aim to be in compliance with the National Spatial Data Infrastructure (NSDI) framework standards promoted by the Federal Geographic Data Committee (FGDC).

2. Integrating transportation data to support business processes in PSRC. These include the Regional Transportation Improvement Projects (RTIP), the Metropolitan Transportation Planning (MTP) system, and data for the transportation model, EMME/2. Between them, these databases contain a variety of transportation data, including Asset Management data such as transit bus stops and transit centers, bridges, functional class, traffic volumes, as well as location referencing for the projects.

GIS has become an integral part of PSRC's day-to-day planning activities, because it is an efficient tool for the analyses required for transportation planning. While nearly every function at PSRC relies on GIS and support from the GIS team, data needs and databases are not integrated in one single GIS system or model. For example, MTP and RTIP data are currently stored in separate Microsoft Access databases. Neither database has a spatial component or a direct link to a GIS feature. The travel demand-forecasting model also stores data in its own specialized data structure, and it too does not have a direct, dynamic linkage to the PSRC GIS. Each PSRC function currently has its own data requirements and relationship to the organization's GIS. As needed, maps can be created on-the-fly by linking the Access data to ArcView GIS. The current situation is depicted in Figure 1.

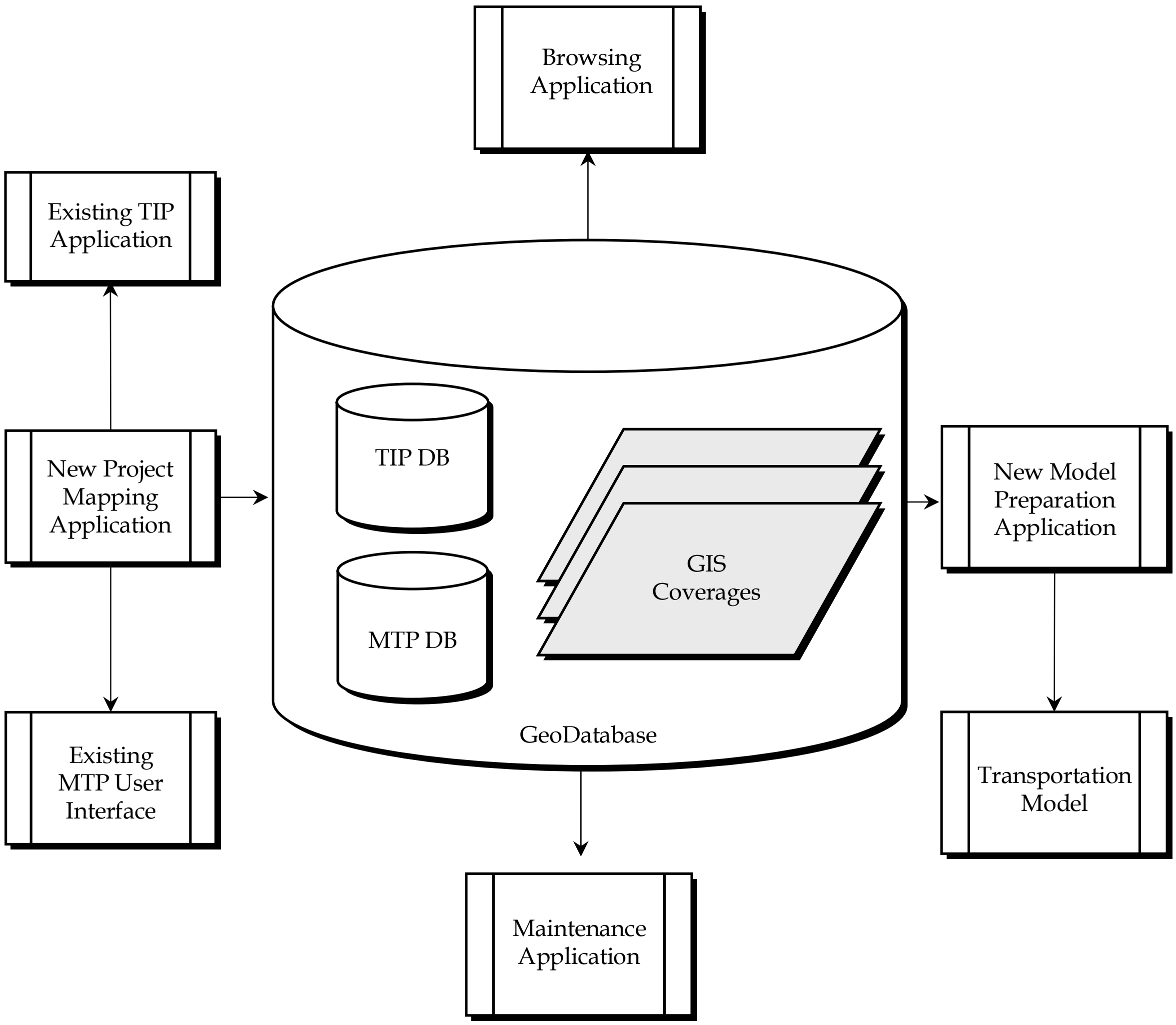
Figure 1. Conceptual View of PSRC's Current Operations



In 2002, the agency began a project to develop an enterprise data model. The objective is to eliminate the unnecessary passing of data between applications, and enable each team to work with a consistent and up-to-date set of geographic features as attribute data is being entered. This requires, some fundamental changes in the current business processes, which PSRC is currently reviewing.

As part of the enterprise data model project, a plan is being prepared to guide the development and implementation of the steps needed for system design and development. The conceptual design for the new system is depicted in Figure 2.

Figure 2. Conceptual Diagram of the Proposed Enterprise System



Implementation of this system architecture is expected to begin in 2003 and continue through 2004.

The Regional Council's Data and GIS sections currently share responsibility for this function. As the enterprise data model is implemented, roles and responsibilities may need to evolve to support the technical changes.

Integrated Data Considerations

As shown in Figure 2, the following functions will be supported by the data integration effort:

- GIS functions, including maintaining the base map and centerlines for highways, transit, and non-roadway features, such as bike paths and ferry routes;
- The MTP database that stores and manages information on transportation planning projects in the region;
- The RTIP database that stores and manages information on transportation improvement projects submitted by member governments but not yet part of the MTP; and
- Travel forecasting data required by the transportation model EMME/2. An integrated database would provide seamless access to RTIP and MTP data for modeling purposes, compared to the manual conversions required at present.

An integrated geodatabase will provide a central data repository for the above applications. They will still have their own interfaces, accessing the geodatabase through some Application Program Interface, mapping interface or both. In addition to the travel demand modeling, RTIP, and MTP applications, there are other potential uses in the agency including land use modeling and financial monitoring applications.

The RTIP and MTP applications will require new Graphical User Interfaces (GUI) for data access and retrieval, and these will probably be coded in Visual Basic.

PSRC does not manage a linear referencing system itself, beyond the geocoding of project locations to street names and addresses; but it does utilize the state's mile point referencing methods for locating project on the state and interstate highways, and the agency has employed linear referencing of project events on routes created in the GIS. The linear referencing of projects and other events (e.g., bus stops) is important for the transportation model. With the implementation of the geodatabase, it is proposed to use ESRI's measured shape files for linear referencing with the GIS.

Integrated Data Architecture

The applications currently use separate Access databases. The GIS uses ESRI GIS software and stores the spatial data as coverages or shape files. The future system's architecture will be built on SQL/Server relational database, with ArcSDE as the middleware managing the geodatabase, and ArcGIS clients or browser clients to the spatial data, the latter served via ArcIMS Internet map server.

Figure 2 shows the overall framework for the enterprise database system. The core geodatabase will manage both the spatial data and attribute data in SQL/Server and ArcSDE. This will ensure data integration between these two data sets, which are currently kept apart. Much of the business data together with the applications interfaces will remain in Access, but will be linked to the geodatabase and be accessible via the new Project Mapping application in GIS. In time, all the data stored in the Access databases will be migrated to SQL/Server. The data migration is being implemented in phases in order to optimize staffing and other resources in this process.

The Maintenance Application will be a GIS module to add/delete/modify network elements, and will have tools to add and edit RTIP and MTP projects directly through the map interface. The new Model Preparation application also will be a GIS module with tools to display model data inputs and outputs. The model preparation will automate the conversion of the MTP and RTIP projects into model format, a process that at present involves several steps. Thus, the geodatabase will support three separate but linked GIS applications in an integrated system. The underlying network architecture, comprising the Windows 2000 operating system and local area network, will remain the same.

The new geodatabase provides an opportunity for PSRC to upgrade its GIS software from the standalone Arc/Info and ArcView programs to an integrated platform comprising ArcSDE on the server and ArcGIS on client workstations. The thick clients are required to run the applications programs. In future, the agency would like to make the data and applications more widely accessible via a thin client Browsing Application on the Internet, using ESRI's Internet Map Server technology (ArcIMS) as the web GIS platform.

■ Lessons Leaned

One of the biggest obstacles to developing an enterprise system is standardization. Standardizing an organization's GIS base map cartography or establishing a common set of geographic layers that will be used throughout the functions of the agency is key to making an enterprise GIS system more efficient. Currently, PSRC's GIS department maintains several different versions of geographic line layers depending upon the need. For example, the GIS team maintains three road networks; one for general purpose uses, one for the transportation model, and another for the TIP projects. Accordingly, there is a lot of redundancy and inefficiency in the datasets. A cleaner approach is to create one reference network and specify those network components that satisfy each function. In addition, it is possible to create routes to represent transportation projects on the network. This approach provides a more integrated and efficient method for coding and managing the network.

PSRC has taken an incremental approach to data integration, focusing on practical improvements that demonstrate its benefits. Lessons learned include taking a step-wise approach to data integration, working as best as one can with the resources available, and not relying too much on technology. Business processes and data needs drive the work of the agency and information systems need to demonstrate their practical application to meet agency goals.

Future Plans

PSRC plans to implement the enterprise GIS project now underway and scheduled for completion in 2004. This project is laying the foundation for the creation of a centralized geodatabase and integrated transportation network to serve multiple applications in the agency.

Once the geodatabase is in place, PSRC can more effectively work with member governments on bilateral data sharing arrangements. For example, city and county governments manage many of the key transportation assets and these are used in RTIP projects and other applications. PSRC has difficulty integrating these disparate data sets without a time-consuming data conflation effort. The new process will improve the data sharing arrangements and simplify the data integration, thereby leading to better support for all transportation data elements.

Likewise, at the state level, PSRC needs to coordinate with Washington DOT, which has responsibility for maintaining many key assets. It is therefore important for PSRC to support the state's Transportation Framework project that will enable data sharing between the two organizations. PSRC will be able to reference state transportation assets in the PSRC region for use in analyzing transportation projects, and likewise WSDOT will have access to RTIP and MTP projects for its STIP and other programs.

References

1. Interviews with Jerry Harless, GIS Manager, Puget Sound Regional Council, February and March 2003.

2. Cambridge Systematics, Inc. *PSRC Consultant Review and Discovery Process*, January 2003.

Acknowledgment

Information for this detailed review was compiled with the assistance of Jerry Harless of Puget Sound Regional Council.

Task 3 – Professional Groups and Organizations Involved in Data Integration

Introduction

As the literature search and detailed reviews indicated, the transportation industry routinely performs data integration activities. Data integration is applied to key elements of operation and management, cutting across organizational and jurisdictional boundaries, transportation modes, customer service objectives, and technologies. A number of public- and private-sector transportation groups are actively addressing policies, methods, and standards related to data integration to derive greater advantage from this concept and to leverage existing information management technologies such as Geographic Information Systems (GIS). These groups influence transportation data integration efforts in three ways: by promoting and sponsoring data integration activities; by adopting and implementing practices, standards, and policies; and by developing data integration architecture.

This report examines how issues and challenges associated with data integration are being addressed by industry groups and professional organizations. Each group is described in terms of:

- Its mission and membership;
- The scope and nature of its work on data integration; and
- Activities and products of the group including conferences, meetings, reports, publications, and research studies.

The industry groups and organizations reviewed here represent the agencies to which Transportation Asset Management will be widely applicable. The following groups/organizations are reviewed:

1. American Association of State Highway and Transportation Officials (AASHTO);
2. U.S. DOT Office of Asset Management;
3. Transportation Research Board (TRB);
4. Intelligent Transportation Systems (ITS) America;
5. Bureau of Transportation Statistics (BTS);
6. Institute of Transportation Engineers (ITE);
7. Open GIS Consortium (OGC);

8. Federal Geographic Data Committee (FDGC);
9. LandXML.org Industry Consortium;
10. Highway Engineering Exchange Program (HEEP);
11. Unified Network and Transportation Consortium (UNETRANS);
12. International Standards Organization (ISO); and
13. Institute of Electrical and Electronic Engineers (IEEE).

■ American Association of State Highway and Transportation Officials (AASHTO)

Contact Information

- **Address**: American Association of State Highway and Transportation Officials, 444 North Capitol Street NW, Suite 249, Washington, DC 20001
- **Telephone**: (202) 624-5800
- **E-mail**: info@aashto.org
- **Web site**: http://www.aashto.org

Description

The American Association of State Highway and Transportation Officials is a national organization representing highway and transportation departments nationwide. AASHTO provides technical services and information to its member agencies and advocates transportation policies and positions on behalf of its membership. Full membership in AASHTO is reserved to the highway and transportation agencies in the 50 U.S. states, the District of Columbia, and Puerto Rico. Federal agencies, foreign agencies, and other regional agencies can have partial (non-voting) membership. The private sector is also encouraged to take part in AASHTO activities.

Data Integration Scope

AASHTO's data integration activities consist of the following.

Task Force on Transportation Asset Management

The role of the AASHTO Asset Management Task Force is to promote and facilitate Asset Management in the transportation community. Asset Management is defined by the Task Force as "optional allocation of resources for the management, preservation, and operation of transportation infrastructure." An important component of Asset Management is "integration of decisions made across all program areas." The Task Force developed a strategic plan in December 2000, which included the establishment of information resources for benchmarking Asset Management practice.

The Task Force sponsors and maintains a Community of Practice web site (http://www.dot.state.ia.us/aashtoam), **Transportation Asset Management Today**, in collaboration with the Federal Highway Administration's Office of Asset Management and the TRB Task Force on Asset Management. The web site provides a forum for exchanging information on Asset Management and part of the discussion board is dedicated to data integration.

The Task Force is chaired by a CEO of a member agency, with voting members comprising representatives of state highway and transportation agencies. Friends of the Task Force include other transportation professionals from the public and private sectors and academia.

Standards Development Organization (SDO) for ITS

Since 1996, AASHTO has served as one of five organizations selected by the U.S. Department of Transportation's Intelligent Transportation System Joint Program Office (JPO) to develop ITS standards.[1] Depending on the standard being developed, AASHTO may either lead as the Standard Development Organization (SDO) or assist as a partner. AASHTO's other roles in developing these standards include maintaining public sector involvement, educating and training others about ITS standards, and helping test standards.

XML in AASHTOWare Products

Efforts are underway at AASHTO to adopt Extensible Markup Language (XML) in the AASHTOWare software product line supported by the organization. AASHTO plans to be more actively involved with other organizations in development and upkeep of XML standards, especially those relating to transportation data. AASHTO realizes that XML offers the advantage of exchanging data more easily between software applications, networks, and platforms. Querying, reporting, and archiving also will be improved with XML. AASHTO wants to make the XML standard and documentation available in the public domain.

Activities and Products

Journals, Reports, and Other Publications

- AASHTO has developed a set of standards and guidelines governing all aspects of AASHTOWare product development.

[1] The other four organizations are the Institute of Transportation Engineers (ITE), the Society of Automotive Engineers (SAE), the Institute of Electrical and Electronic Engineers (IEEE), and the American Society of Testing and Materials (ASTM).

Conferences, Meetings, and Workshops

- **AASHTO and TRB Annual Meeting –** This is held every fall at a location in the U.S. that changes from year to year. The annual meeting allows transportation state officials and other transportation professionals from the public and private sectors to come together and share information on policy and practices in transportation. The AASHTO Task Force, the Transportation Research Board (TRB) Task Force on Asset Management, and the FHWA's Office of Asset Management developed a plan for Asset Management at a national level at a meeting in Providence, Rhode Island, in July 2002.

- **GIS for Transportation (GIS-T) Symposium –** This conference is held every March at a different location in the U.S. Cosponsored with U.S. DOT, the Highway Engineering Exchange Program (HEEP), and the Urban and Regional Information Systems Association (URISA), the annual conference provides the opportunity for professionals to learn and share experiences related to the use of GIS in transportation.

- **National Transportation Asset Management Workshops –** In 1996, AASHTO and the FHWA began cosponsoring a series of workshops on Asset Management practice. These have become major forums for exchanging experience, ideas, and updates of progress in the field. The last conference was hosted by the Midwest Regional University Transportation Consortium and the Midwest Transportation Center in Madison, Wisconsin in September 2001. The 2003 workshops will be held in parallel in Atlanta, and Seattle, in September and October 2003, respectively.

- **AASHTOWare XML Workshop –** This workshop was held in November 2002. Its purpose was to address questions and concerns over the use of XML in AASHTOWare products. The meeting addressed the coordination of XML development and the reduction of redundancies or gaps in product schemas.

Software

The AASHTOWare program includes three major product suites.

1. The Trans*port suite which includes 12 components to support highway/transportation agency pre-construction and construction contract information and management needs;

2. The BridgeWare suite which includes three products to support bridge engineering and management (Pontis for bridge management, Virtis for load rating, and Opus for bridge design); and

3. RoadWare, which includes the Interactive Roadway Graphics Design System (IGrds), the Pavement Design and Analysis System (DARWin), and the Survey Data Management System (SDMS).

These three products are documented in the AASHTOWare Standards and Guidelines Notebook (http://www.aashtoware.org/aashtoware/downloads/notebook.pdf).

■ FHWA Office of Asset Management (OAM)

Contact Information

Address: Office of Asset Management, Federal Highway Administration, U.S. DOT, 400 Seventh Street, SW, Washington, DC 20590

Telephone: (202) 366-0392

Web site: http://www.fhwa.dot.gov/infrastructure/asstmgmt/index.htm

Description

Established in February 1999 by the Federal Highway Administration (FHWA), the Office of Asset Management's mission is "to provide leadership and expertise in the systematic management of highway infrastructure assets." The OAM partners with AASHTO and other FHWA offices in conducting nationwide programs aimed at developing asset management principles and policies.

The OAM is staffed by Federal employees divided into three organizational teams: System Management and Monitoring, Construction and System Preservation, and Evaluation and Economic Investment.

Other FHWA offices also initiate and engage in data integration activities. For example, the FHWA Office of Policy cosponsors the annual North America Travel Monitoring Exhibition and Conference (NATMEC).[2]

Data Integration Scope

Since an important requirement for Asset Management is integrated data, the OAM supports a data integration program focused on gathering, developing, and distributing data integration information. The OAM publishes a variety of documents on data integration, sponsors workshops and conferences, and conducts research.

Activities and Products

Journals, Reports, and Other Publications

- **Data Integration Fact Sheet –** This informational document explains the importance of data integration to Asset Management and summarizes the key concepts of data integration.

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[2] See TRB Conferences

- **Data Integration Primer –** A companion to FHWA's *Asset Management Primer*, this document explains the importance of data integration to Asset Management. Topics discussed include the overall data integration process, implementation, and challenges. Data integration case studies of various state efforts also are presented.

- **Data Integration Glossary –** This glossary provides close to 100 definitions of terms commonly used when discussing databases and information management.

- **Data Integration Forum Proceedings –** A summary of the 2001 forum.

- Several Publications on Asset Management and related topics held in Chicago.

Training

- The OAM works with FHWA's National Highway Institute to develop and promote courses in Asset Management practice and associated management systems, analytic procedures, and uses of information.

Conferences, Meetings, and Workshops

- **Data Integration Forum and Peer Exchange –** This meeting, held in December 2001 in Chicago was sponsored by AASHTO and FHWA's Office of Asset Management and focused on data integration practices. Topics discussed were integration requirements, legacy databases, alternative tools and technologies, data standards, reference systems, and technical/organizational challenges. Participants included transportation professionals from local, state, and Federal agencies and from the private sector.

- **Transportation Asset Management Workshops –** See listings under AASHTO.

■ Transportation Research Board (TRB)

Contact Information

Address: Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001

Telephone: (202) 334-2934

Web site: http://www.trb.org

Description

TRB is an organizational unit of the National Research Council within the National Academy of Sciences and the National Academy of Engineering. It is a private, nonprofit institution with the aim of advancing the transportation field. TRB promotes transportation-related research, exchange of information, and adoption of research findings through the use of technical committees and task forces. Many of the committees found in Division A

(Technical Activities) of TRB include data integration as part of their scope. TRB membership encompasses professionals from local, state, Federal, and international agencies, industry organizations, private sector firms and individuals, and academia.

Data Integration Scope – Technical Committees

Eight different committees and subcommittees of interest are described below.

Statewide Transportation Data and Information Systems (A1D09)

- **Web site:** http://members.tripod.com/~TRBstate

The committee focuses on research activities related to the integration of transportation data from multiple sources into a statewide multimodal planning database. In addition, the committee facilitates discussions and technology transfer related to planning data activities. The committee recently sponsored the following relevant meetings:

- **August 2000 –** Performance Measures – Madison, Wisconsin;
- **March 2001 –** Data Integration – Washington, D.C.;
- **July 2001 –** Adding Value with Data Collection Programs – Vail, Colorado;
- **March 2002 –** Using Spatial Data, Tools, and Technologies to Improve the Delivery of Transportation Programs – Charleston, South Carolina; and
- **May 2003 –** Data Partnerships – Duck Key, Florida.

Task Force on Transportation Asset Management (A1T50)

The Task Force on Transportation Asset Management promotes the use of asset management principles to develop optimal resource-allocation strategies. Asset management principles include engineering economics, business practices, and information systems. The Task Force focuses on the state-of-practice in multimodal asset management across all levels of government. In addition, the task force helps identify research needs, and facilitates information sharing through meetings, workshops, conferences, and publications. The TRB Task Force sponsors sessions on Asset Management at annual TRB meetings and works with the AASHTO Task Force on Asset Management and the FHWA Office of Asset Management developing and implementing research and educational programs on Asset Management.

Information Systems and Technology (A5003)

- **Web site:** http://www.cae.wisc.edu/~trbist

The committee focuses on developments in information technology and the corresponding impacts on the productivity of transportation organizations. New technological developments of interest include data management and sharing, web technologies, common semantics and standards in transportation, technology transfer activities, etc.

Spatial Data and Information Science (A5015)

- **Web site:** http://www.ctre.iastate.edu/trb-sdis

The Spatial Data and Information Science committee focuses on Geographic Information Systems for Transportation (GIS-T). GIS-T refers to both spatial and temporal transportation data, and the use of information systems for managing this data. The committee coordinates GIS-T activities within the TRB. A Subcommittee on Data Integration was recently created under the Spatial Data and Information Science committee. This subcommittee coordinates all aspects of transportation data integration, including technologies, processes, and organizational infrastructure. The subcommittee focuses on identifying and synthesizing practical guidelines and best practices for data integration efforts, and documents approaches and methodologies used by other industries and areas of government.

National Transportation Data Requirements and Programs (A5016)

The committee focuses on the development of national and international data to support decision-making, and research in all areas of transportation. The committee's areas of interest include technical areas such as data acquisition, data analysis, and data dissemination; and administrative areas such as program funding and program coordination. In particular, the committee is interested in coordinating programs in transportation with programs in other areas, as well as coordinating programs varying in scope from national and international to local and state levels. In addition, the committee establishes statistical standards and criteria for guiding transportation programs.

Urban Transportation Data and Information Systems (A1D08)

- **Web site:** http://www.mtc.dst.ca.us/trb/urban

This committee is interested in the design, collection, analysis, and reporting of transportation supply and demand data needed to support urban and metropolitan transportation planning efforts. In particular, the committee is interested in developing the data requirements of new and innovative techniques for measuring and monitoring the performance of metropolitan transportation systems, and in evaluating changes in demographic and urban travel characteristics. With respect to household and other transportation surveys, the committee is concerned with the analysis, reporting, archiving, and dissemination of results and data products. The committee is interested in the effective use of census and other Federal, secondary data sources in metropolitan transportation planning. The committee is also concerned with advancements in information systems and information technology for the improved dissemination and sharing of knowledge about metropolitan transportation systems and urban travel behavior.

Activities and Products

Journals, Reports, and Other Publications

- **TRB e-Newsletter –** This electronic newsletter is geared toward transportation professionals and covers research and development activities in the United States and abroad.

- **Transportation Research Information Services (TRIS) –** The TRIS database contains over 450,000 records of transportation-related research articles, abstracts, and descriptions of ongoing projects. Available online, TRIS is the largest database of its kind on the Internet.

Conferences, Meetings, and Workshops

- **TRB Annual Meeting –** Held each January in Washington, D.C. – This meeting brings together over 8,000 transportation researchers and practitioners from around the world to discuss a variety of transportation-related topics.

- **Technical Committee and Task Force Meetings and Workshops –** Various committees and task forces hold periodic meetings and training sessions throughout the year to enable members to network or discuss ongoing research. At the TRB 2002 Annual Meeting, two workshops were sponsored by the subcommittee on Data Integration under the Spatial Data and Information Science committee, one on data warehousing and the other on determining data value in a disintegrated organization. The subcommittee plans to identify best practices, case studies, and data sharing activities. It also will reach out to the nine other TRB committees that also are studying different aspects of data integration. The subcommittee maintains a site on the main TRB web site. The subcommittee also identified Asset Management as one of the focus areas for its future activities.

- **North American Travel Monitoring Exhibition and Conference (NATMEC) –** This conference, held every two years, aims to advance the state-of-the-practice of travel monitoring by providing a mechanism for improving the interaction among users, data collection, program management, and the staff that collect, process, and use that data.

■ Intelligent Transportation Society of (ITS) America

Contact Information

Address: ITS America, 400 Virginia Avenue SW, Suite 800, Washington, DC 20024-2730

Telephone: (202) 484-4847

Web site: http://www.itsa.org

Description

Created by a 1991 U.S. Congressional mandate, the Intelligent Transportation Society of America (ITS America) coordinates the development and deployment of ITS in the United States. ITS America uses technical committees, task forces, state chapters, and other governing bodies to promote research, develop standards, and disseminate information on ITS. ITS America consists of 60,000 members representing public agencies at the local, state, Federal, and international levels, as well as universities, research organizations, and corporations.

Data Integration Scope

ITS America addresses data integration primarily through two organizational efforts.

System Architecture Committee

This committee deals with issues related to developing and deploying ITS system architecture. A system architecture is a blueprint that defines the general characteristics of an ITS. By creating defined ITS frameworks, coordination improves among all stakeholders. The committee is involved in the development of the National ITS Architecture Plan.

ITS Standards Caucus

ITS America proposed an ITS Standards Caucus to encourage standards development, deployment, and testing. The ITS Standards Caucus combines the former activities of the Council of Standards Organizations and the Standards and Protocols Committee.

Activities and Products

Journals, Reports, and Other Publications

- **ITS America News –** This monthly Internet newsletter provides articles on ITS-related topics and information.

- **Access ITS Web Site –** The web site managed by ITS America allows access to numerous ITS-related reports, articles, and press releases. Also posted on the site are updates on activities of committees and task forces.

Conferences, Meetings, and Workshops

- **ITS America Annual Meeting –** This annual spring meeting is held in various U.S locations to provide practical information and hands on experiences in solving transportation challenges. ITS leaders gather to explore technology solutions, exchange ideas, and hear from experts about the advances that fuel the growth of ITS development and deployment.

- **ITS World Congress and Exhibition –** This conference is held annually in November and the venue changes from year to year and from country to country. ITS America, in cooperation with other international organizations such as the European Road Transport Telematics Implementation Coordination Organization (ERTICO), sponsor an annual ITS showcase at this conference.

- **ITS America Committee Meetings –** Throughout the year individual committees meet to discuss ongoing activities, to share ideas, and to hold training sessions.

■ Bureau of Transportation Statistics (BTS)

Contact Information

Address: Bureau of Transportation Statistics, 400 Seventh Street, SW, Room 3103, Washington, DC 20590

Telephone: (800) 853-1351

E-mail: answers@bts.gov

Web site: http://www.bts.gov

Description

The Bureau of Transportation Statistics is a Federal agency that is part of the U.S. DOT. The role of the BTS is to collect, analyze, and report transportation data for the U.S. DOT As well as to set standards for transportation data. Established in 1992 by the Intermodal Surface Transportation Efficiency Act (ISTEA), BTS is mandated to make cost-effective use of transportation-monitoring resources in a policy-neutral manner while covering all transportation modes. Like the Census Bureau, the BTS is permitted by Federal regulation to confidentially collect information.

Activities and Products

The BTS is working with the Open GIS Consortium (OGC) to develop a prototype web portal for transportation data. This effort will result in the Geospatial One-Stop, which will make transportation geospatial data developed through the National Spatial Data Infrastructure (NSDI) initiative available on the Internet. Anticipated Geospatial One-Stop benefits include:

- Providing Federal, state, and local agencies, and private citizens a common, consistent source of geospatial data;
- Accelerating the development of the NSDI; and
- Lowering data acquisition costs by encouraging partnerships and by improving access to existing data.

Within the NSDI Transportation initiative, the BTS also is responsible for developing content standards for each transportation mode.

Journals, Reports, and Other Publications

- **Journal of Transportation and Statistics –** Published three times a year, this peer review journal focuses on the measurement and analysis of transportation data.

- BTS produces various compact discs containing transportation data (www.bts.gov).

Institute of Transportation Engineers

Contact Information

Address: James M. Cheeks, Jr., Standards Development Manager, Institute of Transportation Engineers, 1099 14th Street, NW, Suite 300 West, Washington, DC 20005-3438

Telephone: (202) 289-0222, ext. 131

E-mail: jcheeks@ite.org

Web site: http://www.ite.org

Description

The Institute of Transportation Engineers (ITE) is a professional organization whose members include traffic engineers, transportation planners, and other professionals involved in transportation planning, design, construction, operation, and maintenance. ITE has both individual and agency-level membership. Agency members include national agencies, state/provincial agencies, regional agencies, counties, and cities. The organization's purpose, as stated in its bylaws, is to facilitate the application of technology and scientific principles to research, planning, functional design, implementation, operation, policy development, and management for any mode of transportation.

Activities and Products

ITS Standards Development Organization

- **Web site**: http://www.nawgits.com/icdn.html

Like AASHTO, ITE has been designated as an ITS standards development organization by the U.S. DOT. ITE is also involved in training and deployment of ITS standards. ITE is part of the ITS Cooperative Deployment Network (ICDN), a shared Internet resource for ITS information.

National Transportation Communications for ITS Protocol (NTCIP)

- **Web site**: http://www.ntcip.org

The National Transportation Communications for ITS Protocol (NTCIP) is tasked with developing a communications standard for traffic control and ITS devices. NTCIP standards will help ensure compatibility between hardware and software products offered by different vendors. The protocol will help optimize the performance of current infrastructure and enable future expansion without excessive reliance on a single vendor or on customized software. The NTCIP is a joint effort by AASHTO, ITE, NEMA, and FHWA with funding from the FHWA. The latest NTCIP Guide (V. 03.02) details the protocol and provides assistance with the implementation of compliant devices.

Advanced Traffic Management Systems Data Dictionary (TMDD)

ITE is leading a national effort to develop a standardized Advanced Traffic Management Systems Data Dictionary (TMDD), with support from AASHTO and FHWA. The TMDD will identify and define the specific data elements used by, and exchanged between, various ITS applications (ATMS, ATIS, etc). The effort is part of the high-priority standards development activities necessary for Intelligent Transportation Infrastructure (ITI) deployment. The effort is being guided by a Steering Committee whose members represent both public and private organizations.

Journals, Reports, and Other Publications

- **The ICDN Newsletter –** The ICDN Newsletter contains up-to-date news and other information on ITS deployment. Published twice a month, the newsletter is also available online.

- **ITE Journal –** Published monthly, the journal provides ITE members with articles on transportation-related topics and ITE activities. ITE journal is also available on line.

Conferences, Meetings, and Workshops

- **ITE Annual Meeting and Exhibit –** The annual meeting, held in August, is regularly attended by over 2,000 transportation professionals. The meeting focuses on community issues, mobility/operations, safety, traffic engineering, transportation planning/transit, and transportation management.

- **Online Standards Forum and ITS Forum –** As part of the ICDN program, these two online forums were created for ITS stakeholders to discuss development and deployment of ITS. The forums are administered and funded by FHWA.

Open GIS Consortium (OGC)

Contact Information

Address: Open GIS Consortium, Inc., 35 Main Street, Suite 5, Wayland, MA 01778

Telephone: (812) 334-0601

E-mail: info@opengis.org

Web site: http://www.opengis.org

Description

Founded in 1994, the Open GIS Consortium (OGC) is an independent organization funded by the GIS industry to conduct research and promote standards for data exchange between vendors and users. Its goal is to make spatial information and location interoperable, advocating an open approach to the development and adoption of GIS-related standards. OGC believes that open standards make it easier for systems to interface with each other, regardless of network, application, or platform. Although the standards OGC creates are not legally binding, OGC's consensus approach to the standardization process attracts widespread adoption of its specifications. OGC involves in its activities over 254 governmental agencies, companies, and universities from around the world.

Data Integration Scope

Interoperability Program

The Interoperability Program of OGC uses different types of targeted initiatives to accelerate the development of OGC specifications and to promote their broader adoption. To aid in development, OGC employs feasibility studies and collaborative applied research, called "testbeds." For outreach and partnering efforts, OGC has initiatives that include planning studies, pilot testing, and "technology insertion projects." An example of a transportation-related initiative is the Geospatial One-Stop – Transportation Pilot (GOS-TP). GOS-TP is a GIS spatial data standardization effort linked to the implementation of National Spatial Data Infrastructure (NSDI). The initiative demonstrates the benefits of partnership between several government agencies and private industry groups to make geospatial information more interoperable.

OpenGIS Specifications

As an organization with an emphasis on open and shared standards, OGC makes specifications available through its OpenGIS Specification products and services.

Specification Program

The Specification Program at OGC is responsible for standards creation. Through the work of technical and planning committees, potential standards are synthesized and developed from the conceptual stage to more detailed specifications. Input from industry is frequently solicited through public requests for comments. OGC also works closely with official standards governing bodies to align development efforts.

Activities and Products

Journals, Reports, and Other Publications

- **OGC News –** This monthly e-newsletter is published for OGC members and provides updates on GIS interoperability issues. OpenGIS products include documentation, technical papers, and discussion papers. OGC also provides software for others to test conformity of their applications with OpenGIS Specifications. Products that conformed to OGC standards can be listed as specification compliant.

- **OpenGIS Specifications –** These specifications available online are standards developed by OGC for use in GIS-related applications.

Conferences, Meetings, and Workshops

- **OGC Technical and Planning Committee Meetings –** About every two months, the committees hold a meeting to enable members to discuss ongoing standardization efforts, network, and hold training sessions.

Federal Geographic Data Committee (FGDC)

Contact Information

Address: FGDC, USGS, 590 National Center, Reston, VA 20192

E-mail: fgdc@fgdc.gov

Web site: http://www.fgdc.gov

Description

The Federal Geographic Data Committee (FGDC), which is part of the U.S. Geological Survey (USGS), encourages the coordinated development, use, sharing, and dissemination of geographic data. A subcommittee on Ground Transportation promotes the coordination of geospatial data for ground transportation-related activities. The FGDC has 19 members drawn from various departments, including the Executive office of the President, cabinet-level agencies, and other independent agencies.

Data Integration Scope

The FGDC is developing a set of policies, standards, and procedures for interagency cooperation in the production and sharing of geographic data, collectively termed the National

Spatial Data Infrastructure (NSDI) framework. As part of this effort, the FDGC Ground Transportation Subcommittee is developing the NSDI Transportation Identification Standards. These are a set of conceptual data model standards that relate to maintenance of road data, and allow road segments to be identified as a unique and independent geo-spatial feature.

Information on the NSDI and other initiatives including the Geospatial One-Stop contents standard for transportation can be obtained from the FGDC web site. This includes reports from the Ground Transportation Subcommittee as well as FGDC standards guidelines such as the Standards Reference Model.

Activities and Products

Journals, Reports, and Other Publications

- **FGDC Newsletter –** The FGDC publishes a newsletter with information on geographic data-related issues three times a year. It has also published several reports on NSDI and other geographic data-related topics. Minutes of the FDGC Steering Committee meetings and the Ground Transportation Subcommittee meetings are available on the FDGC web site.

- **Transportation Identification Standard** – The FGDC Ground Transportation Subcommittee has completed development of a draft of the Transportation Identification Standard. This draft was posted for public comment, and now the subcommittee is reviewing those comments.

- Apart from the FGDC working groups, BTS and other members of the Ground Transportation Subcommittee have publicized the NSDI and GeoSpatial One-Stop initiatives at various conferences. For example, the 2003 Geospatial Information Systems for Transportation Symposium included a session titled "Update on Geospatial One-Stop Activities for Transportation." Similar presentations have been made at TRB conferences and workshops.

■ Data Exchange Standards (LandXML.org)

Contact Information

E-mail: landxml@landxml.org

Web site: http://www.landxml.org

Description

In December 1999, the LandXML.org Industry Consortium was formed by the company AutoDesk to create an open data exchange standard in extensible Mark-up Language

(XML). XML is a programming language that allows information or data to be more easily shared and transmitted over the Internet and between different software applications. LandXML.org comprises over 180 representatives from more than 80 public agencies, private organizations, industries, and universities from around the world.

Data Integration Scope

The XML Schema Version 1.0 is a data standard based on XML developed with three specific uses. First, the standard defines how data transfers for civil engineering and surveying software applications. Second, the schema describes the format for archiving data. Third, the standard specifies the format for electronic design submission. Other uses can be derived such as data format for importing and exporting into GIS databases. LandXML.org complies with the World Wide Web Consortium's (W3C) XML specifications.

Activities and Products

Journals, Reports, and Other Publications

- **LandXML Schema Version 1.0 –** The XML schema was accepted in July 2002 as the industry data exchange standard for civil engineering and surveying information. The specifications are accompanied by documentation.

Conferences, Meetings, and Workshops

- The organization periodically holds workshops to discuss development of the LandXML. More information can be found on the LandXML.org web site.

- **International Highway Engineering Exchange Program (IHEEP) Annual Conference –** Usually held in September at various United States locations, LandXML.org participates in the conference to display its schema development efforts.

■ Unified Network and Transportation (UNETRANS) Consortium

Contact Information

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Organization Description

UNETRANS (Unified Network and Transportation), a consortium headed by ESRI and the University of California Santa Barbara, is developing a generic transportation data model for applications that work with ESRI's ArcGIS software.

Members of this consortium include transit, railway, and aviation agencies on the state and local levels. Transportation professionals, software developers, ESRI business partners, and university researchers are also involved.

Activities and Products

By developing a standard generic database format, UNETRANS hopes to allow users to take better advantage of ESRI's GIS software. The collaborative project has three main components. The first component is the development of conceptual object models to describe transportation features, integrating different transportation modes, and defining scaling representation of objects. Another component of the project involves the creation of a Unified Modeling Language (UML) code for use with ArcGIS. UML is a standard language to aid in describing software system components. The project's third component is documentation of the data model.

Journals, Reports, and Other Publications

- **Online Documentation –** Sample transportation data models, documentation, and databases are available at UNETRANS' web site.

- **Web Forum –** UNETRANS' online web forum allows members to create discussion threads regarding development of GIS transportation data models.

Highway Engineering Exchange Program (HEEP)

Contact Information

Web site: http://www.heep.org

Description

The Highway Engineering Exchange Program (HEEP) is an organization whose purpose is to allow members to share engineering knowledge and experiences, specifically in computer technologies. Founded in 1956, HEEP has grown into an international organization and is divided into five geographic areas. HEEP cosponsors a number of activities with other industry groups and public agencies. Regular membership is open to transportation professionals from local, state, or Federal agencies or from academia. Individuals from the private sector also may participate in HEEP as associate members.

Activities and Products

Conferences, Meetings, and Workshops

- HEEP sponsors an annual international conference (usually in September) to bring together transportation professionals from around the world. The conference allows its members to share their experiences in the use of technologies in engineering, specifically computer-related technologies. Public agencies as well as the private industry are encouraged to highlight their accomplishments and products. Conference participants from the public and private sectors are predominantly from North America and Europe. HEEP is subdivided into five areas. Each of these areas hold periodic meetings throughout the year to enable members to exchange information and experiences on transportation-related topics.

International Standards Organization (ISO)

Contact Information

Address: ISO Central Secretariat, International Organization for Standardization (ISO), 1, rue de Varembé, Case postale 56, 1211 Geneva 20, Switzerland

Telephone: 41 22 749 01 11

Web site: http://www.iso.org

Description

The primary goal of international standardization is to maximize long-term benefits to users, industry, and society by facilitating the exchange of goods and services through the creation and adoption of common technical approaches for trade and commerce. Three bodies are responsible for the planning, development and adoption of International Standards:

- International Standards Organization (ISO);
- International Electrotechnical Committee (IEC); and
- International Telecommunication Union (ITU).

Established in 1947, ISO is a legal association whose members are the National Standards Bodies (NSB) of some 130 countries supported by a Central Secretariat. The principal deliverable of ISO is the International Standard. An International Standard embodies the essential principles of global openness and transparency, consensus and technical coherence. These are safeguarded through its development in an ISO Technical Committee, representative of all interested parties, supported by a public comment phase. Organizations in countries that do not have fully developed national standards activities are entitled to correspondent membership. Countries with very small economies are entitled to subscriber membership.

Data Integration Scope

Technical Committee (TC) 204 Standards

The work of ISO/TC 204 encompasses standardization of information, communication and control systems in the field of urban and rural surface transportation, including intermodal and multimodal aspects, traveler information, traffic management, public transport, commercial transport, emergency services, and commercial services, generally referred to as ITS.

Geographic Data File (GDF)

GDF Version 4.0 (ISO/TR 14825:1996) is a standard for the interchange of digital road-related geographic information. The GDF standard, which is being proposed as the draft international standard, meets all requirements of the Road Transport and Traffic Telematics (RTTT) field and is widely adopted in Europe.

Activities and Products

Journals, Reports, and Other Publications

- **ISO Bulletin –** The monthly publication covers ISO-related activities, standards, committee meetings.

Conferences, Meetings, and Workshops

- **ISO Annual General Assembly –** This meeting is held annually in September with the venue changing countries every year.

- **ISO Technical Committee Meetings –** Various committees hold periodic meetings throughout the year to enable members to develop or discuss ongoing standardization efforts, network, and hold training sessions.

■ Institute of Electrical and Electronic Engineers (IEEE)

Contact Information

Address: IEEE Standards Association, PO Box 1331, 445 Hoes Lane, Piscataway NJ 08855-1331

Telephone: (732) 562-6381

Web site: http://standards.ieee.org

Description

The Institute of Electrical and Electronic Engineers (IEEE) is a non-profit professional association of technical workers in fields such as computer engineering, biomedical technology, telecommunications, electric power, aerospace, and consumer electronics. IEEE has over 377,000 individual members in 150 countries, and is considered a leading authority in these technical fields. The mission of IEEE is to promote the engineering process of creating, developing, integrating, sharing, and applying knowledge about electronic and information technologies and sciences.

Activities and Products

IEEE's Intelligent Transportation Systems Data Registry (ITS-DR) is a centralized data dictionary for all U.S. National ITS Domain-related data elements and concepts. ITS-DR was established to support the interchange and use of data and concepts among various ITS functional areas. The ITS Data Registry Board of Directors (ITS-DR BoD), the body that provides policy guidance for the operation of the registry, is made up of representatives from each organization that supports the registry.

Journals, Reports, and Other Publications

- **IEEE Standards Online –** IEEE produces 30 percent of the world's published literature in electrical engineering, computers, and control technology. To access the wealth of standards publications, IEEE offers an online library of standards for a fee.

■ Summary

The number of industry groups and organizations involved in data integration within the transportation industry indicates the breadth and importance of this field. The development activities and products of these organizations and the rationales underlying their efforts point to the following focus areas for data integration research and programs:

- Standardization of practices, protocols, and conventions governing data storage and communication;

- Maximizing efficiency and cost savings in data collection, processing, storage, and retrieval;

- Promoting greater accuracy and reliability in utilizing data for management and analysis; and

- Enhancing access and visualization of data, and using information to improve the work process.

The broad scope of these efforts and the number of industry groups involved also points to the need to understand the "big picture" in data integration. Data integration can serve a number of management purposes that vary in their informational needs – whether in terms of geographic area, time period, level of precision and accuracy, and relationship to other data. The data integration effort also must respond to economic, technological, legal, and jurisdictional factors, which themselves evolve over time. The implications for particular management initiatives, such as transportation Asset Management, provide a continuing need for data integration and the need to maintain cooperation and partnership with various groups.

Task 4.0 – Innovative Data Integration Practices and Tools

This section summarizes and highlights the more innovative data integration techniques examined in the detailed reviews. The innovative practices pertain to various aspects of data integration including requirements/needs analysis and planning, data storage and access, location referencing, application of Geographic Information Systems (GIS), data standardization, data presentation, web-based implementation, data quality management, and organizational management. All products, methods, and processes described below can potentially be used by any agency to enhance its data integration initiatives. However, while a particular tool or method may work well for one agency, this does not necessarily mean it will have the same impact on another. The purpose of this material is to provide information on what new and innovative tools or methods are available and an example of how each can be used.

■ Requirements/Needs Analysis and Planning

Several agencies have undertaken or are undertaking an in-depth evaluation of their business processes as a precursor to data integration. This exercise has proved to be very effective in determining what they have, what they need, and how data integration will support those needs.

Arizona DOT is completing a six-month business process review/improvement project that will support data integration. The objective is to map the "as-is" core ADOT business processes from Planning to Maintenance. The nine macro-level processes include: Scoping, Priority Programming, Five-Year Plan Update, Design and Pre-Construction, Construction, Maintenance, Program Budgeting, Project Accounting, and Contract Accounting. Each process consists of a description, a linear flowchart, a cross-functional chart, and an information use matrix. The matrix, which maps information use across business processes, will serve as the basis for future data integration activities.

Similarly, Michigan DOT completed a business process redesign of its core and support functions. Initial reviews were focused on MDOT's software and processes that support project and program development. During the review, MDOT discovered that much of the information needed was contained in four large data files. Moreover, these files contained essentially the same information, but were stored and accessed in different ways. Clearly the business process review in this case established the need and framework for a very extensive data integration effort that followed.

Data Storage and Access

One of the major challenges involved in data integration, especially among highway agencies where multiple databases and applications exist, is determining how the integrated data will be stored and accessed. Significant improvement in data server technology has facilitated storage and access of large amounts of data, but for transportation agencies the types and sizes of information (including video and photo images) that are used for Asset Management can still overwhelm the data integration process. The detailed reviews indicate that many agencies have integrated their databases into a central repository commonly called a data warehouse. The data warehouse contains a replica of various databases at other agency locations, providing users access to vast stores of data and a common interface for the relevant subsets of component databases that feed the warehouse. The tools and methods used to store and access data from the warehouse differ from one agency to another. Some of the data warehouses are built on a GIS environment while others have no GIS capability.

For example, Florida DOT (FDOT) maintains a data warehouse consisting of multi-layered GIS spatial databases as well as attribute and image files that come from the FDOT districts. Personal computers connect to the data warehouse server through FDOT's Local Area Network (LAN), Wide Area Network (WAN), Remote Access Server (RAS), or Virtual Private Network (VPN) connections. Users access the system through Internet Explorer. This database enables centralized data management and supports an unlimited number of users.

Arizona DOT is developing an online analytical processing (OLAP) data warehouse system that will serve as a read-only repository of information. An OLAP data warehouse provides fast analysis of shared multidimensional information. It enables users to perform ad hoc queries of large data sets and analyze the results. Users execute queries of the data using Multi-Dimensional eXpression (MDX) instead of the SQL language normally used for relational databases. ADOT is using a mixture of relational and multi-dimensional data models. The resulting data warehouse will provide a one-stop-shop for disseminating accurate information to internal and external users.

While a central data warehouse provided the data integration solution for many agencies (including Colorado, Hawaii, Maine, Minnesota, New Mexico, Tennessee and Virginia, others are looking into linking databases or making databases interoperable using "middleware" or data integration software. For example, the South Carolina DOT is evaluating the method of exchanging data across different databases using the Microsoft BizTalk data integrator. This product is designed to allow integration of legacy applications. The server is capable of receiving data in various formats, saving this original data, and then converting it into a predetermined format to be distributed to users through an interface designed to meet their individual needs. This process is currently being tested for a one-half-mile segment as a "proof of concept" within the agency, and presented to upper management for approval and application to the entire state highway system.

The challenges of storing and managing a significant amount of disparate data (e.g., massive data backups) prompted Virginia DOT to adopt an integrated data architecture that includes two data servers – one for image data and one for business/spatial data. Separating these two types of data enabled VDOT to proceed with its data integration efforts despite the challenges associated with large data sets.

■ Location Referencing

Most transportation assets are described by location. Hence, the system or method used to describe location is an important consideration when integrating asset management data. In any highway agency, a number of location referencing systems are used depending upon the unit that is collecting, managing or reporting the data. As data integration requires a unique or translatable system for indexing location data, many agencies are faced with the challenge of defining and implementing a suitable location reference system. This challenge has been met with a variety of approaches, some fairly standard and others more creative.

A significant number of agencies have developed algorithms or routines that translate data recorded using one reference system to another. Ohio DOT, for instance, developed look-up tables that calculate latitude and longitude coordinates for transportation data that has been referenced using their existing straight-line mile points. Maine DOT maintains two reference systems in its data warehouse but uses a 'static segmentation' method to allow users to perform queries of the data in either system. The Iowa DOT, which currently uses six reference systems, developed a series of algorithms that translate between each of these methods. There is no "standard" referencing system, rather, the system is able to translate data referenced with any of the six methods to the other method.

Michigan DOT's approach, on the other hand, is very different. MDOT abandoned all existing linear referencing systems and adopted a single, statewide linear referencing system. The result was a single road referencing system upon which all transportation features could be referenced. This initiative was a collaborative effort by MDOT and other state agencies including the Michigan Center for Geographic Information. This approach eliminated many of the processing steps that previously occurred between data capture, storage, and dissemination across the State government.

■ Application of GIS

Some transportation agencies are using GIS software not only for mapping, analyzing, and reporting location-based data, but also as a platform for data integration. A variety of commercial GIS software and associated hardware provides the capability to store and manage combined or linked databases. The dynamic segmentation capabilities of many GIS-software products enable data from separate databases to be linked and analyzed.

For example, Hawaii DOT has integrated a wide range of data into a coordinate data system that can be accessed using a GIS tool. As described in the detailed review, the application relies extensively on off-the-shelf database management software and standard GIS software. The system has enabled HDOT to manage and disseminate data more effectively.

Similarly, the Maine DOT developed a GIS-enabled data warehouse system to provide wide access to transportation data for analysis and reporting purposes.

Data Standardization

Data standards facilitate data integration by identifying and establishing acceptable rules for representing, processing, and communicating data. Transportation agencies can adopt industry data standards or develop their own, whichever is more appropriate for their needs. For example, in an effort to improve the integration of planning and maintenance data, the Alaska DOT is developing data collection standards. The desire for GIS mapping capability helped the agency focus the standardization effort on two areas – required location accuracy and measurements of asset attributes.

The Michigan DOT adopted a standard that those data not identified as important would not be migrated or included in their integrated database. All business process owners at MDOT were required to follow this guideline throughout the data integration process.

In its Infrastructure Data Inventory and Needs project, the Montana DOT developed a data dictionary that establishes naming conventions, standard data definitions, and data collection protocols.

Data Presentation

In the same way that data storage and access are important considerations for data integration, the presentation of the data to the users (or clients) makes a significant difference in how effectively the integrated data provides information and supports decision-making in an agency.

For instance, Florida DOT's Geo-Referenced Information Portal supports multiple views of the same integrated data. Views have been developed by business function – e.g., asset management, emergency management, program develop, and public transportation. This approach allows users to view FDOT's integrated data in a way that best supports their actual business needs.

To allow both planning and real-time operations functions across the department, Delaware DOT developed a concept for a transportation workstation that allows users with appropriate authorization to access real-time multimodal transportation management functions including operations, monitoring, and traveler information. This approach maximizes the application of integrated data to day-to-day business operations.

Web-Based Implementation

The World Wide Web is a very powerful and convenient medium for sharing and communicating data across a large number of dispersed users. Many database management software and applications are designed to operate on the web, and more and more transportation agencies as identified in the detail reviews are moving towards web-based database implementation.

The Florida DOT Turnpike Division's Enterprise Asset Management System is a web-enabled, graphically driven desktop application that enables all Turnpike personnel to view integrated data. The application can be accessed using a standard web browser over the Turnpike's intranet. The system provides widespread access to integrated data because only a web browser is needed. It also reduced system maintenance costs since industry standard programming languages are used, and allowed low-cost, seamless integration of data and security through the use of industry standard protocols. The downside of web-enabled tool is the requirement for a robust supporting network.

The Pennsylvania DOT has developed a series of thin-client web applications that enable users to access, query, and analyze its integrated data. For example, one of these tools provides interactive views of multiple roadway attributes including video images.

Data Quality Management

The success of any data integration effort is largely influenced by the quality of the data that the users get from it. Ensuring the accuracy and consistency of integrated data is a major challenge to many transportation agencies especially since data is traditionally collected, stored and managed by different units. To address this problem a variety of approaches have been implemented.

Ohio DOT performed extensive scrubbing of its legacy management systems databases before they were integrated. This "brute force" approach ensured that data inadequacies were not perpetuated in the integrated database system.

Also as part of its data integration effort, Michigan DOT institutionalized data quality by treating data as a corporate asset and informing its staff of the criticality of quality data in program and project decision-making and in the project prioritization process.

Organizational Management

Data integration is an agencywide activity involving various units at all levels of the organization. Many agencies have been successful in coordinating their data integration activities by establishing a group or task force that represents all key stakeholders. The task forces not only ensure that the work is accomplished but also communicate the goals, activities, and outcome of the data integration process to everyone in the agency including upper management. Examples of such task forces include the Colorado and New York DOTs. The CDOT task force is responsible for overseeing the implementation of an Asset Management plan. The task force is headed by the Deputy Director and includes representation from several units in the Department. In New York State the task force was created to develop an Asset Management plan.

In some agencies, the creation of a position specifically designed to oversee the Asset Management program and functions helped facilitate data integration. For example, the Utah DOT appointed an Asset Manager responsible for the technical and organizational components of its Asset Management program. The Asset Manager works with agency stakeholders to define organizational roles and responsibilities with respect to Asset Management, develop an Asset Management framework, and fully implement UDOT's Asset Management program. The creation of this position has helped UDOT emphasize the importance of Asset Management and allocate resources for data integration. In the same vein, South Carolina DOT created a position called Asset Management Program Manager who has been instrumental in developing and implementing its Asset Management Plan.

Clearly establishing roles and responsibilities for those involved in the process is a critical component of any data integration initiative. For the Florida DOT GRIP project, data owners were identified and responsibilities related to data update and accuracy were clearly established. The guidelines require data owners to define and implementing a process to insure the quality of data collection and management.

For data integration involving other organizations outside the transportation department, interagency agreements have helped coordinate and manage multiple activities and responsibilities. One such initiative, the Washington State DOT's Transportation Framework project, established a partnership and bilateral agreements between member governments and WSDOT. The Puget Sound Regional Council (PSRC) is one of the partners. By participating in the State's Transportation Framework project, PSRC will be able to reference state transportation assets in its region for use in analyzing transportation projects. Likewise WSDOT will be able to access the PSRC data.

Task 5.0 – Conclusions and Recommendations

The research study and synthesis of data integration practices contained in this report provide a wealth of information to those agencies that are undertaking or considering a similar effort. It is not a comprehensive review of data integration initiatives across the country but it presents a general picture of the state-of-the-practice. Many agencies that are developing Asset Management plans or are in the process of implementing those plans can learn from the data integration experiences described in this report.

This section summarizes the research findings and provides recommendations for future data integration case studies. The summary is organized by the same headings as the detailed reviews in Section 2.0.

Summary of Data Integration Practices

History/Background

All 27 agencies examined in this study are undertaking data integration activities to achieve efficiencies in data collection and dissemination practices, and to provide better decision-support capabilities. Asset Management is a priority for many of those agencies, but it is not always the primary motivating force for data integration. However, it is generally understood that data integration is an essential requirement for Asset Management.

Most agencies are dealing with disparate data sources in mainframe flat files, redundant data, stovepipe management systems, and functional area barriers. Most recognized a need for data integration in the mid to late 1990s, and some such as Iowa and Kansas developed GIS Strategic Plans. Others do not have formal GIS plans but are using GIS to integrate spatial data with business data. The availability and widespread use of GIS has significantly advanced opportunities for data integration.

Maine was one of the first states to develop a data integration system. This system, called the Transportation Integrated Network Information System, was developed in early 1970s. Tennessee was also early in its attempt to integrate data with the Tennessee Roadway Information Management System, first developed in 1973.

The two most common state DOT offices concerned with data integration and Asset Management are Planning and Information Technology. Florida, Colorado and Montana have established high-level IT committees within their agencies to deal with IT issues and manage the data integration initiatives.

Many states included in the detailed review emphasized the need for interagency data sharing. Washington has an interlocal agreement with Puget Sound called the Washington

State Transportation Framework. Minnesota is attempting to share traffic and safety data with local governments in the State, and Iowa has partnered with Des Moines metropolitan counties to develop a road centerline database.

Integrated Data Considerations

The detailed reviews revealed several common integrated data considerations in the areas of functionality (how integrated data are used), approaches to integration of legacy data, and location referencing methods.

Functionality

The common objective of transportation data integration is to provide decision-makers with easier access to timely and accurate information. Agencies have customized their integration efforts to support decision-makers in almost every area of DOT operations (e.g., policy development, planning, program development, program implementation, operations, maintenance, etc.).

In order to provide easier access to information, agencies have developed tools with the following functionalities:

- Provide canned analysis and reporting routines;
- Enable ad hoc queries (both tabular and spatial) and reports;
- Export results to common desktop applications;
- Generate maps;
- Combine a map, images, and highway characteristics in an interface that enables users to “drive” along a stretch of roadway and view pertinent data;
- Provide multiple levels of access to the integrated data; and
- Provide support for integrated needs identification and investment analysis.

When integrating data, transportation agencies often try to avoid the need for replacement of existing applications and facilitate greater reuse of legacy data. New tools often serve to integrate and disseminate data while leveraging existing technology and infrastructure.

Legacy Data

A critical early step in the data integration process is to identify existing data sets and decide what data should be integrated. One approach is to develop an enterprise data model that maps data items to their sources and to the business functions that they support. Agencies have integrated a wide range of data types (e.g., relational databases, spreadsheets, flat files, video logs, traffic data, and data collected with global positioning systems) to support various functions. In some instances these integrated data have been maintained by state, local, Federal, and private organizations.

Location Referencing

Location referencing is typically the backbone of transportation data integration efforts. State DOTs have integrated legacy data that are referenced using a variety of linear referencing systems (LRS) such as segments, reference posts, stationing, literal descriptions, and route-milepost. The use of multiple location referencing methods is a common data integration challenge.

There are three general approaches to integrating data with different LRSs:

1. Standardize on a single LRS to be used throughout the agency (e.g., data collection, storage in all legacy systems, reporting, etc.);

2. Maintain legacy data in multiple LRSs and create routines to translate these data into a common LRS for the purpose of integration; and

3. Develop an exchange engine that translates data between various LRSs (with this approach there is no common or standard LRS).

Integrated Data Architecture

The most common architecture used by transportation agencies to integrate data is a centralized data warehouse system illustrated in Figure 5.1. Highlights of this approach include:

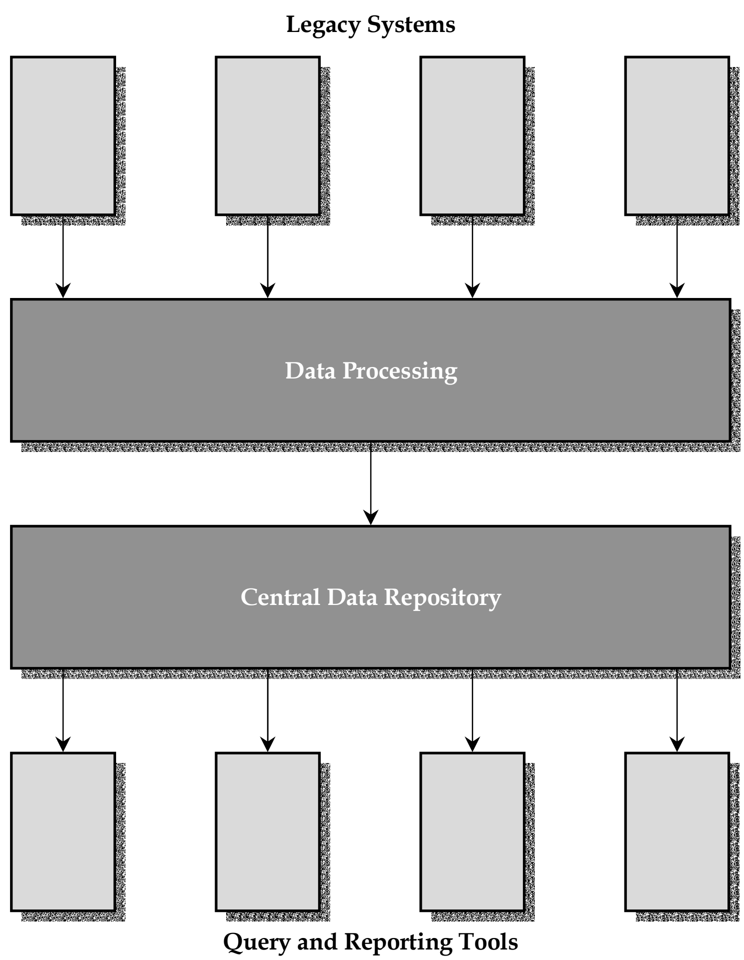
- Source data are stored and maintained in individual management systems;

- Data are extracted from these systems using common exchange protocols [e.g., Structured Query Language (SQL), Extensible Markup Language (XML), open database connectivity (ODBC) protocol, etc.] and processed (normalized, referenced to a single LRS, etc.);

- Processed data are stored in a central data warehouse; and

- Users access data in the warehouse using a series of query and reporting tools, which often include a GIS application.

Figure 1. Common Conceptual Architecture



Variations and enhancements to this architecture have been found in the following agencies:

- The Iowa DOT uses the same general architecture except that one of its management systems (the Pavement Management Information System) stores and processes the data directly in the central data repository;
- Due to size limitations, the Virginia DOT's data warehouse consists of two servers – one for business and spatial data, and one for images; and
- Integrated data architectures that do not involved central data warehouses have also been identified. For example, South Carolina, Delaware, New York, and Pennsylvania DOTs are planning to develop middleware (i.e., a series of interfaces or exchange engines) that enables direct links between various legacy systems.

The detailed reviews indicate that transportation agencies generally choose their integrated data architecture based on the following considerations:

- Phased implementation can be the most practical approach to data integration. Manageable increments with well-defined products enable an agency to minimize technical risks and quickly illustrate practical benefits;
- The architecture should be open and flexible enough to accommodate both changing data requirements and future technologies. Several agencies have found that adherence to Federal guidance and industry protocols have provided this flexibility; and
- The approach to system development should strike a balance between the realization of strategic objectives, the ability to develop practical applications, and the resources required for future maintenance and operations of the system.

Lessons Learned

The agencies identified a large number of lessons and insights that are valuable to other agencies undertaking a data integration initiative. The lessons can be grouped into the following areas: upper management support, role of the Information Technology (IT) department, business process reengineering, user needs, buy-in, off-the-shelf versus custom applications, data quality, linear referencing system, data warehousing, training, process, and link to Asset Management.

Upper Management Support

Most agencies stressed the importance of upper management commitment in overcoming organizational hurdles and securing funding. While the "bottom-up" driving force for integration is often strong and can provide the impetus for moving forward, it can be uncoordinated, particularly across divisions. In Florida, a variety of institutional issues were identified during the development of their Geo-Referenced Information Portal including the need to obtain buy-in related to the benefits of such a system. These issues were overcome with clearly established guidelines and full executive support. Michigan, like other states, learned that data integration champions at the highest levels of the organization can ensure a successful outcome.

Role of Information Technology (IT) Department

In any data integration activity, it is important to have a solid IT vision and architecture, because technology becomes rapidly obsolete, and it is burdensome and inefficient to rewrite computer programs every few years. Florida and Alaska recognized that enterprise data needs to be identified and managed in a similar fashion as human resources and capital assets. Ownership must be assigned and standards must be set. Collection and processing rules must be documented and available.

Data ownership and accountability played a key role in Arizona's data integration efforts. To this end, the agency helped operational units (planners and engineers) understand that they "own" the data they collect and are responsible for its integrity. IT staff are merely "custodians" of the data, and the data warehouse merely a tool with which to access the data.

In Maine the Information Systems (IS) staff works in partnership with other agency staff to promote data integration. They recognize that in some cases DOT employees need to develop separate databases in order to do their jobs. Specific IS roles there include development of an Enterprise Information marketing strategy to make employees aware of available data and the benefits of integration, providing advice and support on collection and use of data; and early, substantive involvement in new application development projects – particularly those involving outside contractors.

Business Process Reengineering

In Alaska and Michigan it was recognized that data disconnects were symptoms of suboptimal business processes. Since streamlined business processes improve information flow and result in improved decision-making and agency performance, these states embarked on business process redesign with an end result being better integrated data.

User Needs

Another critical success factor is the ability to meet user needs. Examples of how this was addressed by transportation agencies include:

- In Florida, all data is made available to all DOT offices;
- Maine recognized that data should be made widely available in order to discourage others from creating redundant data collection procedures and databases; and
- Michigan realized that it was essential to design databases and applications that were flexible enough to accommodate the changing data requirements of the user.

Meeting the system users' needs is the only way to sustain the shared data concept in any agency. This will prevent users from going "outside" the system because they do not understand or cannot use the shared data. A combination of education and facilitation to make the systems and databases user friendly must be included in the implementation plan.

Buy-in

Most agencies indicate that obtaining buy-in from users is critical to the success of a data integration program. For example, Florida demonstrated the benefits of Asset Management in general and their data integration tools in particular to potential users to obtain support.

In New Mexico, the major lesson learned during the development of IDEAS relates to project support. Early buy-in for IDEAS was accomplished by the prompt release of a prototype application.

Off-the-shelf Versus Custom Applications

In most data integration efforts, a key decision appears to be whether to develop an application from scratch or to purchase an off-the-shelf product. Given the broad range of asset management activities in a DOT it is difficult for any one product to provide a comprehensive solution. Typically, a mix of off-the-shelf and custom applications are used. From a technical point-of-view, KDOT's decision to rely heavily on off-the-shelf software components and industry standards was a critical success factor. Project staff also leveraged the continual advancements in technology over the course of the project. Major technical hurdles that were identified when the project began in 1996 were addressed with standard software solutions just five years later. Other states have similar success developing custom data integration solutions.

Metadata

When beginning a data integration initiative, there may be strong support for building a data dictionary and meta-data (documented description of the data) layer first. While many agencies acknowledge that it is important to define a common data dictionary and carefully document each data element, some agencies recognize that this can be a major, time-consuming undertaking which can delay achievement of visible results. For example, Arizona DOT was concerned about losing stakeholder interest in its data warehousing effort, and has chosen to pursue data dictionary development in parallel to delivering an analytic tool.

Data Quality

Data quality is a significant issue for many of the states. It is important to obtain good understanding of data needs, including the level of required accuracy and to agree on the best method for obtaining data. As an example, Maine collects data electronically and as close to the source as possible in order to best preserve data integrity.

Linear Referencing System

A major data collection challenge is obtaining a geo-referenced inventory of the assets, so integrated data collection processes are being developed using photogrammetry, Global Positioning Systems (GPS) and innovative field data collection techniques.

In Maine, no single location referencing method served all the data managers well. Therefore, rather than requiring everyone to adopt a single method, the agency is relying on mechanisms to allow location synchronization and cross-referencing of information collected with different referencing methods.

Data Warehousing

One key data warehouse principle is not to alter the original data from the source. Data "transformation" should be limited to little more than geo-coding, or cleansing the geographical information (route, milepost, and offset). It is also critical to create buy in from data owners so that they understand the importance of changing their systems to validate data at entry.

Based on the Virginia DOT's experience with data warehousing, the agency identified the following lessons:

- Choose the software based on the data model;
- Understand the data model;
- Define business requirements and rules in relationship to the data model;
- Start with the smallest possible asset data sets; and
- Prototype business requirements and push them through the system.

Training

Many states recognize and emphasize the importance of user training for data integration systems. One of the key lessons learned from the Delaware DOT's DelTrac experience was the need for ongoing staff training to support the implementation and operation of the program. Michigan, Florida, and California also emphasized the need for users to have sufficient training to understand how to use the tools provided.

General Process

From the detailed reviews the following general lessons on data integration were obtained:

- Getting started:
  - Ensure careful planning, cooperation, and coordination;
  - Develop and document a detailed work process, communicate this to staff, and follow through with it;
  - Promote a balance between strategic planning, practical applications, and future maintenance and operations requirements; and
  - Develop project objectives that include keeping up with latest technology advancements as they became available.
- Managing the data integration effort:
  - Adhere to, and allow for, periodic reviews of the strategic plan;
  - Maintain a detailed schedule;
  - Report and communicate results regularly to stakeholders;
  - Provide for frequent interaction between developers and users at all stages of development;
  - Develop a GIS plan that focuses on the problems but does not constrain the solutions;
  - Determine actual benefits and cost savings;
  - Take an incremental approach – perform one data integration step well, secure the benefits, and then move to the next step;
  - Document data structure and available applications in order to facilitate use and understanding of the system by data customers;

- Resolve organizational issues before any work begins;
- Ensure that the organization's project management structure includes all levels of staff within the department;
- Develop new processes to provide a coordinated approach to collection and use of data; and
- Create an environment that supports process driven activities.

- Other helpful hints:
  - Pursue major steps, create a basic infrastructure for data during good fiscal times, then make incremental improvements;
  - Promote training and technology transfer;
  - Emphasize outreach and public relations efforts;
  - Realize that at some point there are diminishing returns from integration; and
  - Understand that the benefits of integration will lag its implementation.

Asset Management Link

Many of the agencies reviewed recognize the vital link between data integration and Asset Management. Asset Management systems must effectively support decision-making, so it is critical to define these decision-making processes prior to fully developing the support systems. NYSDOT is an example where the program update process has been established as the business process within which key asset management tradeoffs are made. They are pursuing the following approach:

- Focus efforts on assets that the agency wishes to include in tradeoff analysis, and on those for which data collection programs and stovepipe management systems are already in place;
- Establish a common measure for comparing investment candidates; and
- Use an economic evaluation method to compare candidate project proposals.

Future Plans

The future plans of transportation agencies can be summarized under the following areas: status of efforts, management issues, and technical issues.

Status of Efforts

- All are progressing toward the goal of integrated data;
- Most are in prototype and moving to true implementation;

- Most have not yet linked roadway attribute data to financial management systems, however, they are moving in that direction; and
- All realize the benefits of data integration for Asset Management including the positive impact on decision-support systems.

Management Issues

- Plans vary from hiring in-house staff to manage the program (e.g., New Mexico) to hiring consultants (e.g., Delaware with RFP for integrating legacy ITS data). Approximately one-half of the agencies examined hired consultants to supplement in-house efforts;
- Most are paying close attention to customer needs (i.e., data consumers);
- Some were able to quote end dates for projects, however, most were not;
- Some efforts were in a state of flux due to budget concerns;
- Several agencies are focusing attention on institutional roles and responsibilities with respect to data. For example, Montana will recommend a data management organizational structure and Maine DOT has established specific roles for data owners;
- All are continuing to work closely across offices (partnerships within agencies); and
- Few mentioned their approach to GASB 34 although those that did are using the modified approach.

Technical Issues

- Most have already developed a solid IT foundation for future efforts;
- All are fine tuning their linear referencing systems;
- Most continue to move toward migration to Oracle DBMS; and
- Some (Tennessee, Florida and Alaska) are working on data files and GPS coordinates coming directly from field inventories for direct uploading to databases.

■ Case Study Recommendations

The detailed reviews of data integration practices presented in this report contain a great deal of information regarding the approaches used by agencies to integrate data, as well as the elements of their Asset Management programs. Case studies that describe in more detail the issues, strategies, tools, and outcomes of state data integration efforts and how they impact the Asset Management process will be valuable to other agencies.

Transportation agencies that have undertaken (or are undertaking) a data integration initiative and have developed (or are developing) an Asset Management implementation plan are good candidates for detailed case studies. These agencies include Arizona, Colorado, Michigan, Montana, New York, Virginia, and Washington State. Other agencies that have expressed commitment to the Asset Management process and to data integration include Alaska, Delaware, Florida, Ohio, Pennsylvania, South Carolina, Utah, and Vermont. These agencies are likewise potential candidates for the case studies.

It is recommended that the case studies be prepared using the detailed reviews as background materials. Additional information from the agency and other existing documents will have to be collected to develop an in-depth study of the data integration experience.

The format recommended for the case studies is as follows:

- Executive Summary;
- Agency Facts;
- Background (setting the stage):
  - What did the state have in terms of data integration?; and
  - What did they want?
- How they accomplished their goals:
  - Overall approach; and
  - Technical approach.
- Description of challenges and benefits;
- Lessons learned;
- Future Plans;
- Closing thoughts; and
- List of contacts for further information.

These comprehensive case studies, combined with this *Review of Data Integration Practices* report will provide an outstanding set of resources for other states embarking on data integration practices in support of Asset Management.

To access an electronic version of this publication, visit our FHWA web site
http://www.fhwa.dot.gov/infrastructure/asstmgmt/diindex.htm

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