# NCHRP

## SYNTHESIS 385

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

# Information Technology for Efficient Project Delivery

*A Synthesis of Highway Practice*

TRANSPORTATION RESEARCH BOARD
*OF THE NATIONAL ACADEMIES*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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# Information Technology for Efficient Project Delivery

## *A Synthesis of Highway Practice*

**CONSULTANTS**
JOHN JEFFREY HANNON
and
TULIO SULBARAN
University of Southern Mississippi
Hattiesburg, Mississippi

**SUBJECT AREAS**
Pavement Design, Management, and Performance and Materials and Construction

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## NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.



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## FOREWORD

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

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

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

## PREFACE

*By Gail Staba*
*Senior Program Officer*
*Transportation Research Board*

This synthesis identifies "best practices" for the seamless sharing of information throughout all phases of the project delivery process. Best practices were reported by survey respondents and through literature review in the department of transportation (DOT) Planning, Design, Procurement, Construction, and Operations and Maintenance functional areas, including procedural, institutional, human, and technical constraints and mechanisms. Principal investigators surveyed DOT information technology and project/program management professionals on DOT data exchange practices. After analysis of the data, several DOTs were selected for close inspection case studies. The results of these surveys, along with a review of literature published on the subject of data interoperability associated with project lifecycle processes, constitute the basis of this report.

Information presented in this report was derived from a survey questionnaire and supplemented by a literature search, as well as a DOT case study.

John Jeffrey Hannon and Tulio Sulbaran, University of Southern Mississippi, Hattiesburg, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

# CONTENTS

# INFORMATION TECHNOLOGY FOR EFFICIENT PROJECT DELIVERY


## SUMMARY

A National Institute of Standards and Technology (NIST) study was conducted in 2004 to study and quantify efficiency losses in the U.S capital facilities industry resulting from inadequate information technology interoperability. Interoperability in this report is defined as the ability of two or more systems or components (software applications) to exchange information and to use the information that has been exchanged. The NIST study included design, engineering, facilities management, and business process software systems, as well as redundant paper records management across all facility life-cycle phases (commercial, institutional, and industrial construction market segments). In this 2004 study, Gallaher et al. state:

> Interoperability problems in the capital facilities industry stem from the highly fragmented nature of the industry, the industry's continued paper-based business practices, a lack of standardization, and inconsistent technology adoption among stakeholders . . . $15.8 billion in annual interoperability costs were quantified for the capital facilities industry in 2002. Of these costs, two-thirds are borne by owners and operators, which incur most of these costs during ongoing facility operation and maintenance (O&M). In addition to the costs quantified, respondents indicated that there are additional significant inefficiency and lost opportunity costs associated with interoperability problems that were beyond the scope of our analysis. Thus, the $15.8 billion cost estimate developed in this study is likely to be a conservative figure.

In light of what has been defined as a very large problem by agencies such as NIST, the U.S. Department of Commerce, the General Services Administration, the Construction Industry Institute, the FIATECH consortium (fully integrated and automated technology), the International Alliance for Interoperability, and the Construction Sciences Research Foundation, NCHRP commissioned this synthesis report to study interoperability issues specifically related to state departments of transportation (DOTs). Although the capital facilities industry is not an exact metaphor for the public transportation design and construction process, the issues of data interoperability are comparable on most levels (internally and externally) to transportation agencies. Quantification of costs resulting from interoperability issues in the transportation sector is outside the scope of this report.

The synthesis scope aimed at identifying "advanced processes" for the seamless sharing of information throughout all phases of the project delivery process, including procedural, institutional, human, and technical constraints and mechanisms. After a national survey of broad DOT data exchange practices was performed, several DOTs were selected for close inspection case studies. The results of these surveys, along with a review of literature published on the subject of data interoperability associated with project life-cycle processes, constitute the basis of this report.

The synthesis consultants and NCHRP Topic Panel, during the course of the study, agreed to define advanced processes as the measure of how well the DOTs performed data-sharing and interoperability efficiency in three areas:

1. Internally within the DOT organization,
2. Externally with the project stakeholders, and
3. Across the project life-cycle stages.

Efficiency is defined as

1. The ratio of the output to the input of any system.
2. Skillfulness in avoiding wasted time and effort (Information Technology Company 2007; WordNet3.0).
3. A management idea that asserts that there is a technique, method, process, activity, incentive, or reward that is more effective at delivering a particular outcome than any other technique, method, process, etc. (Wikipedia 2007).

For the purposes of this synthesis, advanced processes are determined as the techniques and processes discovered from literature review, survey, and case study within the time and resource constraints of the project. There is little doubt that given more time and investigation that many more occurrences of advanced processes being performed by other DOT agencies could be revealed. Other agencies performing digital processes were identified; however, there was neither the time nor resources available to investigate.

The synthesis, however limited in its scope, has revealed some pertinent findings, as follows:

- In general, agencies are transitioning to digital (versus electronic) data exchange as software applications and changes in work (business) processes enable them to do so.
- Purely digital data exchanges currently are most prevalent in the design functional areas and the procurement functional areas.
- The concept of three-dimensional (3D) design models for sharing data is emerging in the transportation sector. Several agencies reported applications of 3D design models with specifications to govern.
- The 3D design model concept, transportation information model (TIM), appears to be adopted in only the early stages of the transportation construction project life cycle. Little activity is reported in the procurement, construction, or operations and maintenance functional areas.
- Transportation agencies may be uniquely suited to embrace the TIM concept, in that as with building information modeling, the process is owned and driven by the project owner.
- Enterprise resource planning systems have emerged *separately* for agency central business functions (finance, human resources, etc.) and project design and construction functions.
- Mechanisms or technology have not yet been adopted for storing/archiving data within the project model for future or successive iterations of the project life cycle.
- The concept of "smart jobsites" is emerging with wireless hardware, networks, and digital exchange of data occurring on transportation agency construction projects.

Advanced processes discovered in the DOT *planning* functional area are:

- Use of global positioning system (GPS) technology in the creation of a digital terrain model.
- Use of the digital terrain model as the basis for the design function's creation of a 3D design model and for sharing with the construction contractor for stakeless machine grading (also utilizing GPS).

Advanced processes discovered in the DOT *design* functional area are:

- Production of a 3D design model for sharing with the successive DOT functional areas and other project stakeholders (both internal and external).
- Standardization of 3D design model production; that is, specifications that create standard computer-assisted drafting layers composed of specific object groups.

- Selection of software applications that allow interoperability with diverse model datasets.
- Creation within the design functional area of a culture that is dedicated to the transformation of existing business processes toward the TIM concept.

Advanced processes discovered in the DOT *procurement* functional area are:

- Synchronization of design changes between digital and non-digital drawings.
- Synchronization of digital design drawings with all contract documents.
- Statutory allowance of design professional's drawing approval stamp in electronic format.
- Creation of all contract documents from the TIM.
- Capability to perform electronic bid lettings.
- Synchronization of all bidding and award data with TIM datasets.

Advanced processes discovered in the DOT *construction* functional area are:

- Sharing of 3D design model datasets with the construction contractor for layout and stakeless (GPS) machine grading.
- Creation of specifications addressing the contractor's use of TIM model datasets (as-built datasets that the contractor is required to contribute to the model and legal aspects of the datasets themselves; that is, precedence of electronic data versus 2D paper data, etc.).
- Creation by the agency of wireless networked jobsite communications (smart jobsite), where the DOT agents/representatives and other contract stakeholders have access and contribution in real time to TIM data.

An advanced process discovered in the DOT operations and maintenance functional area is the ability to archive and retrieve all construction project datasets within the TIM.

One result produced from the synthesis study is a conceptual model of data creation, storage, and retrieval for the transportation project life cycle. An integrated process model (IPM), designed from work processes (actual or anticipated) from all the DOT functional areas, utilizes the multidimensional TIM throughout all the construction project's life-cycle stages and is shared by all the DOT functional areas and project stakeholders.

The synthesis study also revealed the following barriers to the attainment of the IPM:

- Software application interoperability is one of the largest impediments to the TIM concept.
- Dataset standardization is required not only for TIM consistency, but also for data exchange to occur at all (software application interoperability). This also influences the ability of agencies to transform business processes (workflow) toward the IPM objective.
- There are varying rates of technological adoption and capability across DOTs.
- There are varying rates of technological adoption and capability between project stakeholders (owners, prime contractors, subcontractors, suppliers/vendors, utility organizations, and other agencies).
- Standard technologies concerning storage of large volumes of data in a TIM are only now emerging.
- Standard technologies that define the data being exchanged (metadata) are emerging only now.
- Some impediments to the TIM concept, as follows, are not technical:
  - Legal;
  - Lack of quantified, documented return on investment (concept is a priori);
  - Rate of software application development;
  - New requirements of human resource skills, knowledge, and mindset;
  - Lack of functional understanding (of model delivery concept); and
  - Lack of emphasis on process improvement techniques.

CHAPTER ONE

# INTRODUCTION

As the National Institute of Standards and Technology (NIST) quotation states in chapter one, there are currently potential estimated savings of billions of dollars that can be realized by increased efficiency (interoperability) of delivering design and construction to the capital facilities industry. The project delivery systems in the transportation sector are similar in structure to the vertical construction sector and typically involve similar (if not more) data collection and software systems, so that potential dollar savings can be significant to U.S. public infrastructure costs. The technology is currently available for U.S. transportation agencies to begin sharing in these efficiencies resulting from data interoperability. In most, if not every, agency situation, changes in work-flow processes, investments in new technology and human skill sets, and proper strategic planning will be required to realize financial savings.

Most of the agencies studied and/or interviewed were aware of at least some very significant rewards for the "pain" of attempting change in their organizations. Most were very practical in their expectations and proud of their accomplishments (however incremental) on their way to these projected process efficiencies. The agency managers are quite aware of the infrastructure construction demands within their state boundaries and the competition for the financial capital to deliver the projects.

This synthesis study is designed to assist transportation agencies in becoming more efficient by reporting its findings in the following areas:

- Advanced processes of digital information flow through department of transportation (DOT) functional areas are described.
- Through a national survey of DOT agencies and telephone and conference interviews, selected business practices are described and diagrammed by functional areas of the transportation construction project life cycle [planning, design, procurement, construction, and operations and maintenance (O&M)].
- Digital data-flow "bottlenecks" (gaps) and possible solutions are identified.
- Selected DOT business functions are diagrammed showing the flow of digital data in their respective efforts to deliver transportation projects. Software and hardware resources are identified.
- Broad information on the current state of technology that allows software programs (digital data) to interface together (interoperability) is included.
- As a result of a literature review of approximately 200 documents, basic interoperability problems and solutions are described.
- Broad information on the current state of digital data standardization efforts that enable digital data interoperability is reviewed.
- As a result of the literature review, there is documentation of various efforts both within and outside of the transportation sector on how digital data can be created, utilized, and stored regardless of which software program, functional area, or project life cycle it passes through.
- DOT functional area business practices that enable digital data flow and therefore theoretically increased efficiency are presented.

The most impressive (efficient) practices for project design and construction delivery are borrowed from either case studies or literature to visualize by means of a diagram of the most efficient model for digital data delivery through all of the transportation construction project life-cycle stages (integrated process model or IPM).

- Human resource skills and knowledge that will be required to achieve the IPM are presented.
- The technical and management skills that will be required of DOT staff for the possible requirements of re-engineering existing business work-flow practices and maintaining efficient digital data exchange in the ever-changing software and hardware technology advances are reported.
- Extensions of research beyond the scope of this study are mentioned.
- Finally, the study suggests additional areas of research revealed by the small "snap-shot" of information provided by this synthesis.

Transportation agencies are complex organizations. Although there are differing types of transportation agencies (federal, state, municipal, and specifically dedicated), this synthesis report is concerned with state-level agencies that are state-specific DOTs or turnpike authorities. The report is aimed at discovering the level of efficiency with which the DOTs perform digital transactions. Although this involves studying software applications and electronic data types, it is important at the offset to introduce, even to those already familiar with the processes and functions of these agencies, the scale, depth, and timelines involved with DOT agency information technology (IT) transactions.

A sample list of essential and typical functions of a state DOT are as follows (Boyd et al. 2005):

- Transportation planning and policy;
- Research;
- Grants management;
- Transportation data, modeling, and simulation;
- Geographic information systems and mapping;
- Engineering;
- Construction management;
- Contracts administration;
- Maintenance;
- Inspection and repair;
- Traffic control;
- Incident management;
- Intelligent transportation systems;
- Enforcing compliance with federal regulations;
- Enforcing compliance with state regulations;
- Administering tax, fee, and levy programs and collecting funds;
- Licensing vehicle operators and commercial carriers;
- Supporting law enforcement by providing information on licenses and commercial carriers;
- Issuing permits for restricted vehicles and carriers;
- Supporting military movement of goods;
- Inspections and safety regulations;
- Hazardous materials spills clean-up and oversight;
- Administrative services;
- Financial services;
- IT services;
- Legal;
- Human resources;
- Civil rights;
- Internal audits;
- Coordinating with local agencies;
- Coordinating with other state agencies; and
- Coordinating with the federal government.

In addition to functional complexity, state DOTs are organizationally complex, as shown in a typical organization chart in Figure 1.

Further complication with data sharing and communications may result because the DOTs have established satellite offices throughout their state borders to manage construction and maintenance operations. These separate offices create gigabytes of information daily that are eventually reported and/or stored at headquarters.

Because of the organizational complexities and variations that exist among state DOTs, the synthesis panel believed it was necessary to limit the focus of this synthesis study.

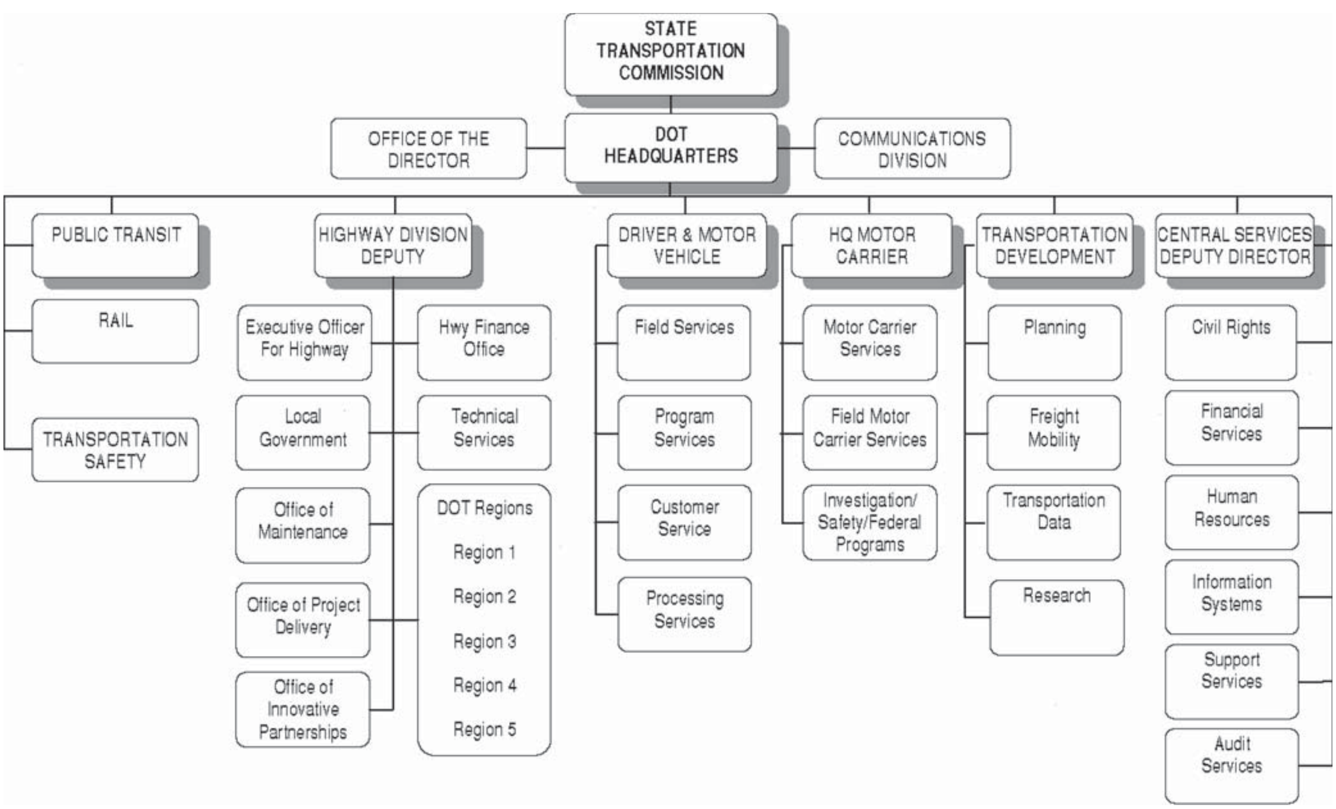


FIGURE 1 Generic DOT organizational chart.

The scope was therefore defined to target only those agency functions concerned with construction project design and delivery.

As "owners" (stewards of taxpayer funds) of the state infrastructure, DOTs are tasked (typically) with the planning and design of construction infrastructure projects. Although the physical construction services are contractually awarded to private-industry contractors, the DOTs select the contract delivery methods (design-bid-build, design-build, etc.), inspect the construction work for quality assurance and quality control (QA/QC), and define the aggregate project construction durations for the contracts. Once the construction contractors have completed their contractual portion of the work, the DOTs typically assume maintenance and operations responsibility for the facility.

For the purposes of this study, the DOT agency functions pertaining to construction project design and delivery have been subdivided into five principal areas of functionality. These functional areas do not represent the organizational structure of all DOTs, as some have these distinct functionalities absorbed into fewer (or additional, more specific) functional areas. In this report, our subdivisions match the project life-cycle stages shown in Figure 2, and represent the following functions:

- Planning: The development of project design alternatives (feasibility) once a need has been identified. Also responsible for initial location and positioning data (location surveys) (D. Streett, New York State DOT, personal communication, May 31, 2007).
- Design: The selection and detailed refinement of project alternatives regarding scope and design (D. Streett, New York State DOT, personal communication, May 31, 2007).
- Procurement: Development and delivery of contract documents; selection of the prime contractor to build the project; and administration of construction, maintenance, and operations contracts and project management of the transportation projects.
- Construction: Inspection of project materials and methods for compliance with minimum project quality specifications, and jobsite and administrative contract administration.
- O&M: Stewardship of the constructed and opened facility.

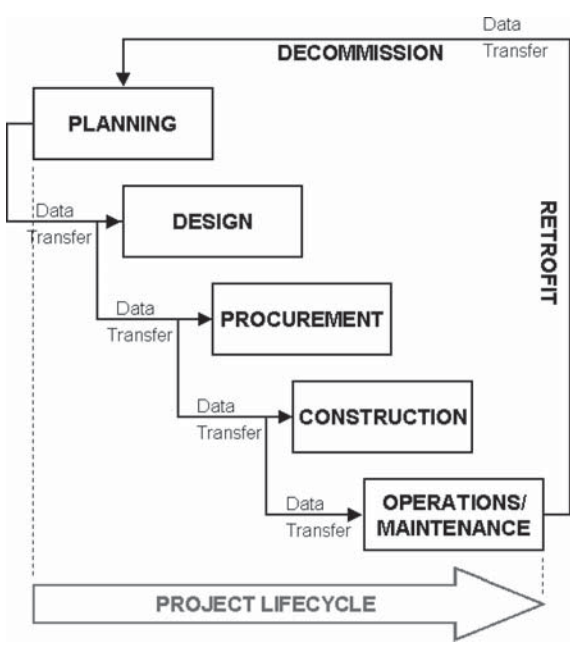


FIGURE 2 Transportation facility life-cycle stages.

As advanced processes for the seamless sharing of information throughout DOT project delivery are identified, it is also necessary to define project delivery stages, also referred to as the project life cycle. The stages or phases are linear in process. That is, ideation and feasibility must precede design, and design must precede construction, etc. Contractual delivery methods such as design-build procurement can alter the timing of each stage's total completion (segmentation), but the overall process is linear. Figure 2 displays the stages involved in transportation project delivery.

The phase diagram in Figure 2, with the exception of property acquisition, is typical for any construction facility, horizontal (transportation) or vertical. Best practice construction management requires the passing of data from one life-cycle stage to another. If this passing of data and information between the stages is not efficient or accomplished, it must either be re-created or re-entered into the dataflow. This typically occurs as software applications utilized to generate project data in one stage do not communicate with applications and programs used in another stage or by other contractual stakeholders of the project.

Contractual stakeholders are the parties contractually joined to accomplish the project life-cycle stages and typically include an owner, designer, contractor, subcontractors, and vendor/suppliers as displayed in Figure 3. In the case of public-sector transportation projects, data must also be exchanged between federal, municipal, regulatory, and utility organizations.

Therefore, the delivery of a transportation construction project requires a large amount of data communication (sharing) both within each stakeholder's organization (internally), among the stakeholders' organizations (externally), and across the project life-cycle stages. This study isolates some of these processes and procedures within owner DOTs. The efficiency with which an organization accomplishes this data sharing might be termed "advanced processes."

Consider finally the breadth or scale of the data involved, generated daily by the project stakeholders across the project life-cycle stages. Some of these internal data are revealed on

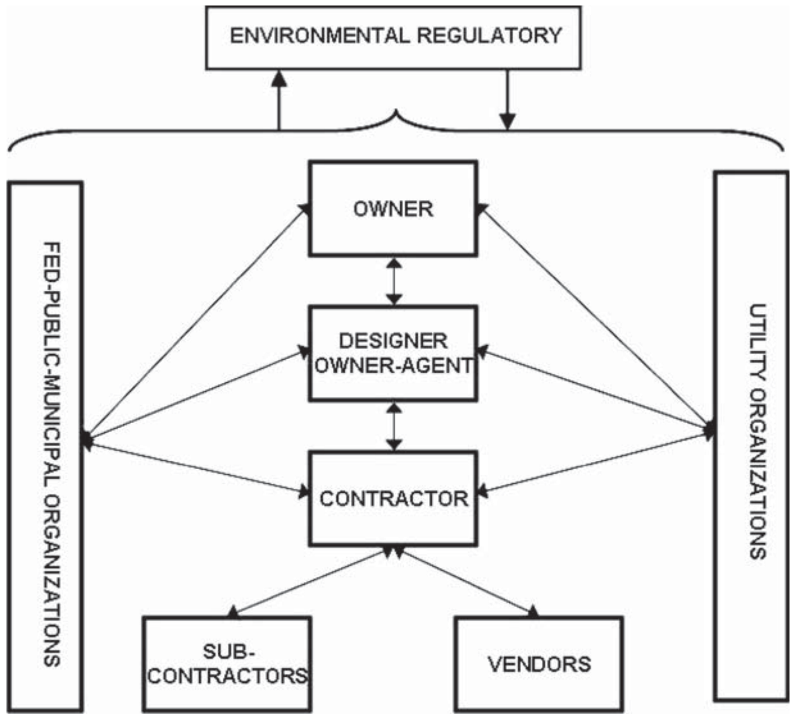


FIGURE 3 Contractual stakeholders and communication lines.

the work-flow process diagrams. These data must be shared and/or archived properly and timely for efficient project delivery. The ability to quickly recall specific data from the mass of data and information generated and stored during the life-cycle stages, without duplicating data entry, provides the basis of managerial decisions that can shorten the stages of the project life cycle (lessening inconvenience to the traveling public) and enhance economic development.

This study, through literature review, survey questionnaire, and DOT case study, identifies the following in relation to transportation project design and construction:

- Identification and reporting of agencies that have instituted creative and efficient methods of productivity in the production of their functional area deliverables (advanced processes).
- Identification of barriers and challenges involved in the attempts to efficiently process transportation design and construction data throughout the project life-cycle stages (and therefore the five defined functional areas). This involves business/work processes, software application interoperability, and strains on agency resources.
- IPM, which is an idealized process map of the most efficient work processes, interoperable software applications, hardware, and agency resources for the delivery of transportation construction processes. Its basis is the literature review and the amalgamation of the advanced processes discovered in the various functional areas.
- Recommendations for further research to extend this area of study.

Some definitions are required for comprehension of the following chapters specific to functional areas and our conclusions. A brief introductory explanation on data file formats of software applications (computer programs) is appropriate before discussing data interoperability. There are three main types of computer programs:

1. Operating systems: these programs function at the lowest level (or machine level) and interpret inputs (keyboard, mouse usage, etc.) and outputs (to peripherals such as printers and monitors) between the user and the computer hardware itself.
2. Interpreters and compilers: these programs convert high-level computer languages into machine language that the operating system can interpret. Computer programs such as a video games, web browsers, spreadsheets, etc., are written in high-level "code" languages such as C, C++, BASIC, FORTRAN, Lisp, etc. Compilers read the program language (software code) and convert it to a binary format or language (utilizing switches of 0s and 1s).
3. Applications programs (or software applications): these are the computer programs that most of us are familiar with; they include all computer programs that are not operating systems or compilers.

It is important to point out that software languages, once learned, can be interpreted by anyone who knows the language (in the same manner of our human written languages). Therefore, if one knows the C++ language and happens to view a program's written language (also known as "source code"), one would be able to decipher exactly how the program is designed to work and function. The user could even change or alter the source code to make the program perform additional or different functions (features). However, once the source code is compiled into binary format, the architecture of how the program is designed with the program language becomes hidden. That is to say, it is impossible to learn how a software application is designed or how it functions by observing compiled binary code.

These concepts are important to interoperability in the following way: If end-users of computer programs could observe the source code, then they would have the ability to alter the programs to create customized features and uses and/or more importantly to interact with other programs more easily (i.e., to make two or more programs interoperable with each other).

There are groups of programmers and users who believe it is unethical for computer software to be sold, licensed, or distributed in binary format. Instead they distribute software in the source code format and allow the end-user to compile the programs themselves. This allows the end-user to manipulate the program's source code to cause the compiled program to serve their specific needs and requirements. These two main groups are referred to as the Free Software and Open Source Software movements. Their differences lie in how they value restrictive software licensing, copyright and patent laws (related to software production), and software development methodologies.

Proprietary software developers typically distribute their software applications in binary format for competitive advantage. The programs are licensed to the end-user, typically per number of users and possibly for limited periods of time. Any changes in a program's functionality must originate from the proprietor's programmers (source code). This situation causes the end-user to be dependent on the software vendor in several ways, as follows:

- If the end-user wants to customize a software application to match unique business processes, the end-user will be dependent on the vendor's development schedule, the vendor's willingness to make the changes, and the cost of development and licensing.
- If the end-user stores data in the proprietor's software application format, then long-term storage, access, and retrieval of the user's data are dependent on access to the proprietor's software application. Not only are there monetary licensing issues involved, but the user risks separation from the data if the vendor goes out of business, ceases to upgrade the software application when newer operating systems become necessary, etc. The end-user could be locked out of access to the data if stored in and dependent on a proprietary software program's binary file format.

Therefore, we have provided the following definitions here and in the glossary that appears at the end of this report.

File format—a specific method of compiling information in a software application file.

Open file format—a published specification for storing digital data, usually maintained by a non-proprietary standards organization, and free of legal restrictions on use. For example, an open format must be implementable by both proprietary and free/open source software, using the typical licenses used by each. In contrast to open formats, proprietary formats are controlled and defined by private interests. Open formats are a subset of open standards. The primary goal of open formats is to guarantee long-term access to data without current or future uncertainty with regard to legal rights or technical specification. A common secondary goal of open formats is to enable competition, instead of allowing a vendor's control over a proprietary format to inhibit use of competing products. Governments have increasingly shown an interest in open format issues (Wikipedia 2007).

Open source software—a high-level software source code of software applications that is distributed before compilation into binary form.

Proprietary file format—a program file compiled in a method specific to a proprietary software developer.

Standard file format—an open file format that has been specified by a standards organization to which free, open source, and proprietary software developers voluntarily adhere to.

These definitions are useful for interpreting some of the tables in succeeding chapters and in the discussion in chapter eight.

CHAPTER TWO

# DATA COLLECTION AND CRITERIA FOR IDENTIFICATION OF ADVANCED PROCESSES

The intended methodology of data collection associated with this study consisted of an initial survey questionnaire that would identify DOTs for successive in-depth interviews. A draft questionnaire was created and distributed to DOTs of the Synthesis Panel participants. The draft questionnaire was then refined with Panel member recommendations and approved for dissemination to the entire pool of DOTs. This questionnaire is Appendix A.

The final survey consisted of a series of redundant questions grouped by DOT functional areas (planning, design, procurement, construction, and operations/maintenance). The intention was to plant the survey initially with a "champion" who could route the survey to persons knowledgeable to complete their specific functional area's questions. Once all survey questions were answered by all five functional area sections, it was to be returned to the consultants for review and compilation.

This plan required persistence to ensure that the questionnaire was partially completed and routed through several functional areas, to the appropriate personnel, gaining acquired information throughout its route within the DOT organization. This was originally to be performed with a web-based survey software application provided by NCHRP. Technical difficulties with serving the application and problems with persistence issues forced the survey to another format.

The survey questionnaire was converted and delivered in an Adobe Acrobat Version 8 file. This format was chosen for its ability to provide the persistence feature and a unique feature that allowed the questionnaire data (not the file itself) to be forwarded to the investigators by means of e-mail once the entire survey was completed.

Nonetheless, there were considerable issues with the survey and the responses to it. The Adobe file itself may have been too large for sharing through e-mail between departments, some were returned only partially completed, there were multiple responses from the same business function with differing answers, and there was inconsistency with how the survey was returned to the investigators.

The survey was initially sent by means of e-mail broadcast to members of the AASHTO Committee on Construction, and then to DOT contacts who were not members of the committee. The response to the survey, after five e-mail campaigns and four months, is shown in Table 1 and Figure 4.

As a result of the survey data and recommendations from Synthesis Panel members, the following four states were initially selected for detailed interviews and data-flow diagramming:

- Florida DOT (FDOT),
- Kentucky Transportation Cabinet (KYTC),
- Minnesota DOT, and
- New York State DOT.

In an attempt to save time and get the synthesis project back on schedule, the decision to contact these four agencies was made before all of the survey questionnaire data were received. Therefore a disparity exists between agencies that were actually interviewed, and some of the final survey results that reveal several agencies with high digital scores which would have been included in the study given more time and resources.

The consultants weighted the agency responses and developed a digital score based on the number of functional areas reported and the instances and magnitudes of digital data transfer. This methodology can be viewed in Appendix B.

Based on the survey responses, an interview form was generated for the in-depth interviews (see Appendix C). Oklahoma DOT was interviewed in an effort to develop a standardized interview form and generic Integrated Definition 0 (IDEF0) diagram for each functional area; however, this was dropped once the interviews began as the processes were not necessarily matching generic or functional area formats.

This report uses the IDEF0 flowcharting method. IDEF methodology is a suite or family of methods that is capable of modeling activities, functions, information, and processes of an enterprise and its business areas. An example of IDEF0 flowcharting can be seen in Figure 5.

TABLE 1
AGENCY SURVEY RESPONSES BY FUNCTIONAL AREA

| Agency | Responses Received by Functional Area | | | | |
|---|---|---|---|---|---|
| | Planning | Design | Procurement | Construction | Operations and Maintenance |
| AK DOT | • | • | • | • | • |
| AL DOT | • | | | | |
| AR DOT | • | • | • | • | • |
| CA DOT | • | • | • | • | • |
| CT DOT | • | • | • | • | • |
| FL DOT | • | • | • | • | • |
| GA DOT | • | • | • | • | • |
| HI DOT | • | • | • | • | • |
| IA DOT | | | | • | |
| IN DOT | | | • | • | |
| KS DOT | • | • | • | • | • |
| KYTC | • | • | • | • | • |
| MD DOT | • | • | • | • | • |
| MI DOT | • | • | • | • | • |
| MN DOT | • | • | • | • | • |
| MT DOT | • | • | • | • | • |
| NE DOT | | | • | • | |
| NH DOT | • | • | • | | |
| NM DOT | • | • | • | • | • |
| NY DOT | | • | • | | • |
| OK DOT | • | • | • | • | • |
| OR DOT | • | | • | | |
| PA Turnpike | • | • | • | • | • |
| SC DOT | • | • | • | • | • |
| SD DOT | • | • | • | • | • |
| TN DOT | | | | • | • |
| TX DOT | • | • | • | • | • |
| VA DOT | | • | | • | • |
| WADOT | Survey Prototype Only | | | | |
| WI DOT | | | | • | |
| WY DOT | • | | • | • | • |
| Total Agencies | Totals by Functional Area | | | | |
| 30 | 23 | 23 | 25 | 26 | 22 |

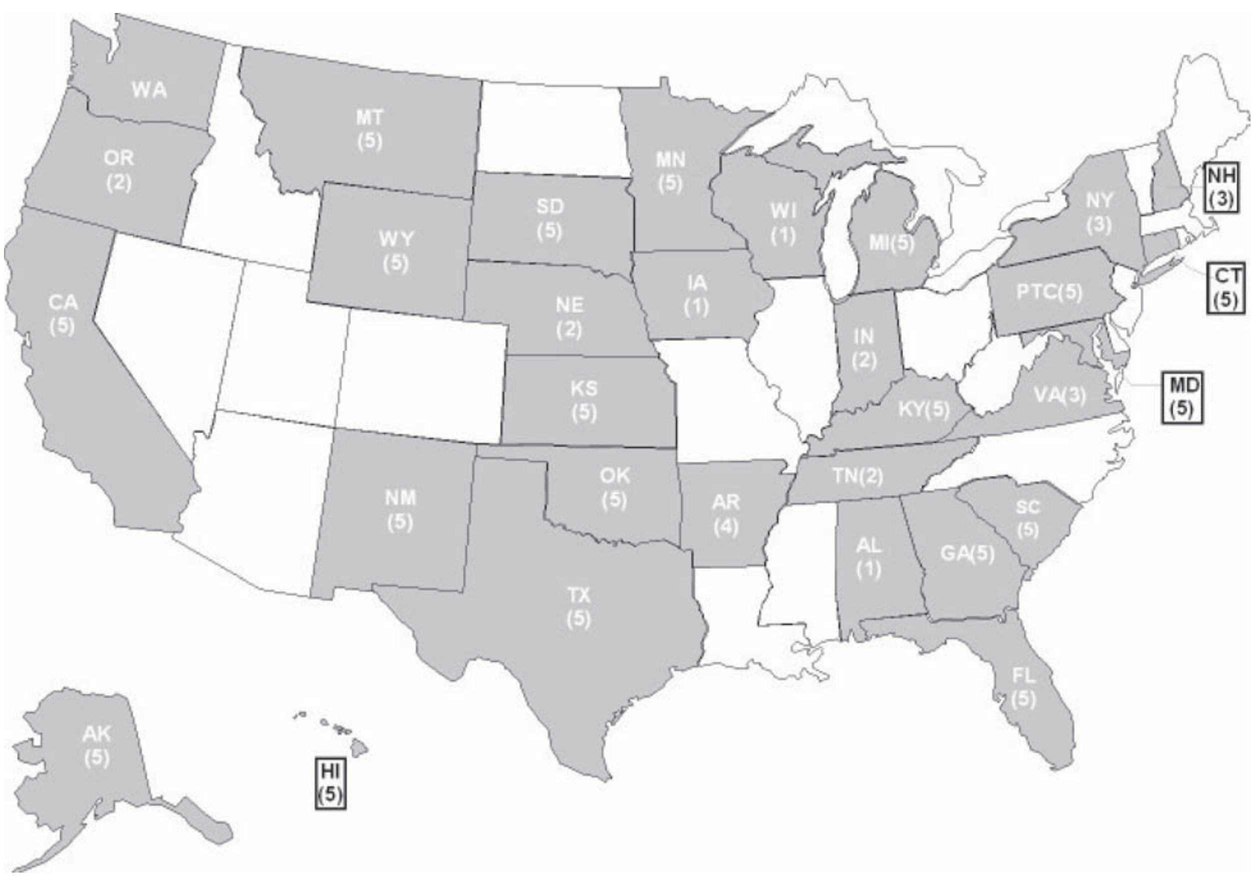


FIGURE 4 Agency survey responses with functional area completions in parentheses.

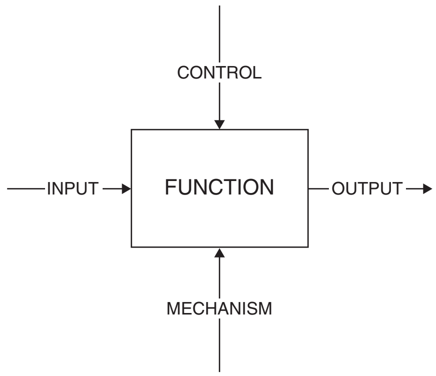


FIGURE 5 IDEF0 charting example.

For IDEF0 diagramming purposes in this study, a function will be defined as primary tasks performed by the functional units or an activity that transforms inputs into outputs.

- Input is defined as information (data) that is required to perform a function.
- A control is a condition or circumstance that constrains a functional activity.
- A mechanism is a person, machine, or software application that performs a functional activity.
- An output is the product of a function and possibly the input to a successive function.

CHAPTER THREE

# INFORMATION TECHNOLOGY FOR PLANNING

## FUNCTIONAL AREA DEFINITION

The planning functional area is primarily responsible for project initiation and feasibility study as well as collecting data for the design functional area for decision making. Daniel Streett of the New York State DOT describes its functional area as a pre-design unit that collects data for the development of project alternatives.

## PLANNING FUNCTION DELIVERABLES

Responses to the survey questionnaire revealed the deliverable types or datasets shown in Table 2 as being received, processed, or sent through the planning functional area. Responses are indicated by two numbers: response count followed by percentage of total responses for the functional area.

For example, according to Table 2, 18 agencies reported receiving location survey data, 15 agencies reported that they process or generate (originate) these data, and 15 agencies reported that these data are transferred to another functional area for use.

Also included in the responses shown in Table 2 are responses inserted into the survey's open-ended text boxes titled as "Other" indicating additional information/data received, processed, generated, or sent from the planning functional area. The questionnaire is included for review in Appendix A, and tabulated results of the survey are available in Appendix B.

## ADVANCED PROCESSES

The advanced processes defined for the planning functional area are derived from both literature review and case studies. In this initial project stage, both of the DOT planning functions that were studied developed the process of creating three-dimensional (3D) terrain models of the project site. This not only sets the stage for addition of the 3D design model in the successive functional area, but also is used in the creation of a digital terrain model (DTM) for eventually sharing with the contractor. The contractor benefits by the ability to incorporate global positioning system (GPS)-enabled earth-moving operations.

In addition, GPS software and hardware, along with interoperable software, hastens the early development of the 3D model by creation of the DTM with fewer human resources than previously required for surveying.

The New York State DOT (NYSDOT) performs a best practice in this functional area by creating a 3D terrain model of the project's surface. This practice is efficient because it serves two main purposes that reduce input procedures and efforts internally, externally, and across the project's life cycle.

- Internally: The 3D terrain model is passed to the design functional area where the balance of the project's design is implemented (added to). This reduces redundant data extraction from the terrain model into additional iterations of computer-aided design (CAD) files (only layers are added).
- Externally: The 3D terrain model is eventually shared with the contractor, allowing them to perform jobsite layout functions electronically and allowing the contractor to produce its own set of cross sections. This reduces DOT resources required to plot and print cross-section plans. Resources are saved on the contractor's side because it can utilize the 3D terrain model for GPS layout and machine grading control.
- Life cycle: The 3D terrain model acts as the shell for a 3D design model that can follow the project's life-cycle stages acting as an information repository (allowing input and extraction of data throughout the project's life).

*Case Study #1 NYSDOT*

- *Work-Flow Process Diagram*. Figure 6 displays a data work-flow diagram as communicated from the NYSDOT case study.
- *Software Applications Utilized.* Table 3 displays the software applications and data formats extracted from the IDEF0 diagram for the NYSDOT planning functional area.
- *Hardware and Networks.* A continuously operating reference station (CORS) network is required to carry and measure GPS signals for verification and creation of survey markers.
- *Challenges and Process Adjustments.*

TABLE 2
DATA RECEIVED, PROCESSED/GENERATED, SENT FROM DOT PLANNING FUNCTIONAL AREAS

| Data Type | Receive | Process/Generate | Send |
|---|---|---|---|
| Location | 18–78% | 15–65% | 15–65% |
| Traffic | 17–74% | 20–87% | 14–61% |
| Environmental | 14–61% | 12–52% | 13–57% |
| Survey | 11–48% | 9–39% | 7–30% |
| Other Data: | | | |
| Roadway Characteristic | | 1–4% | 1–4% |
| Materials Information | 1–4% | 1–4% | |
| Pavement Management | 1–4% | 1–4% | 1–4% |
| Pavement Survey | 1–4% | 1–4% | 1–4% |
| Highway Features | | 1–4% | |
| Highway Centerline | 1–4% | 1–4% | 1–4% |
| From Outside Agencies | 1–4% | 1–4% | |

NYSDOT reported difficulty with interfacing the software applications Bentley Microstation and ESRI GIS (geographic information system).

*Case Study #2 Kentucky Transportation Cabinet*

- *Work-Flow Process Diagram*. Figure 7 shows a data work-flow diagram for a planning functional area (source: Case Study KYTC).
- The KYTC planning function work-flow process is shown in Figure 7 as a contrast. Advanced processes internally include Extensible Markup Language (XML) that is used whenever possible for data export and import between software applications.
- *Software Applications Utilized*. Table 4 displays the software applications and data formats extracted from the IDEF0 diagram for KYTC planning functional area.
- *Hardware and Networks.* Linux and Microsoft Windows 2003 Server networks are utilized.
- *Challenges and Process Adjustments*. KYTC reported the following challenges in the planning functional area:
  – Traffic data printed from mainframe computer not easily accessed or analyzed.
  – An increase in network security that often restricts access to needed data.
  – In-house personnel who have limited software skills.
  – Processing time for statewide traffic models that appears excessive.
  – An interoperability between software applications.
  – Inconsistencies with the overall systems graphical user interface (GUI).

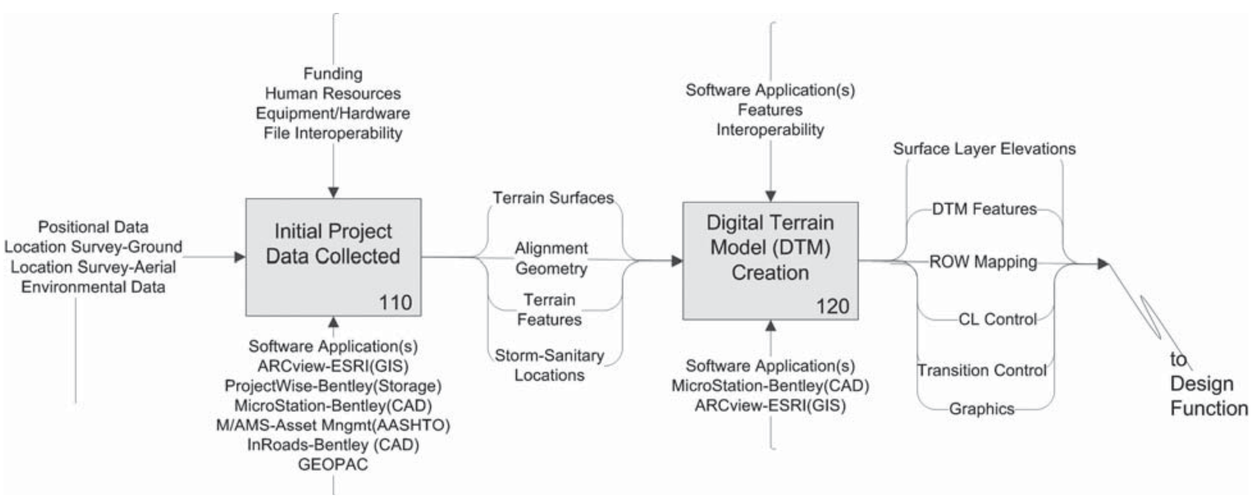


FIGURE 6 NYSDOT data work-flow diagram for planning functional area.

TABLE 3
SOFTWARE APPLICATIONS AND DATA FORMATS USED BY NYSDOT PLANNING FUNCTIONAL AREA

| Application | Software Application-Vendor | Data File Formats |
|---|---|---|
| ROW Mapping | InRoads—Bentley | Open |
| CL Control | InRoads—Bentley | Open |
| Transition Control | InRoads—Bentley | Open |
| Surface Layer Elevations | InRoads—Bentley | Open |
| DTM Features | InRoads—Bentley<br>GEOPAK—Bentley | Open |
| GIS | ArcView—ESRI | Proprietary/Open |
| File Storage | ProjectWise—Bentley | Proprietary |
| CAD | MicroStation—Bentley | Proprietary |
| Operations/Maintenance Asset Inventory | M/AMS—AASHTO | Open |

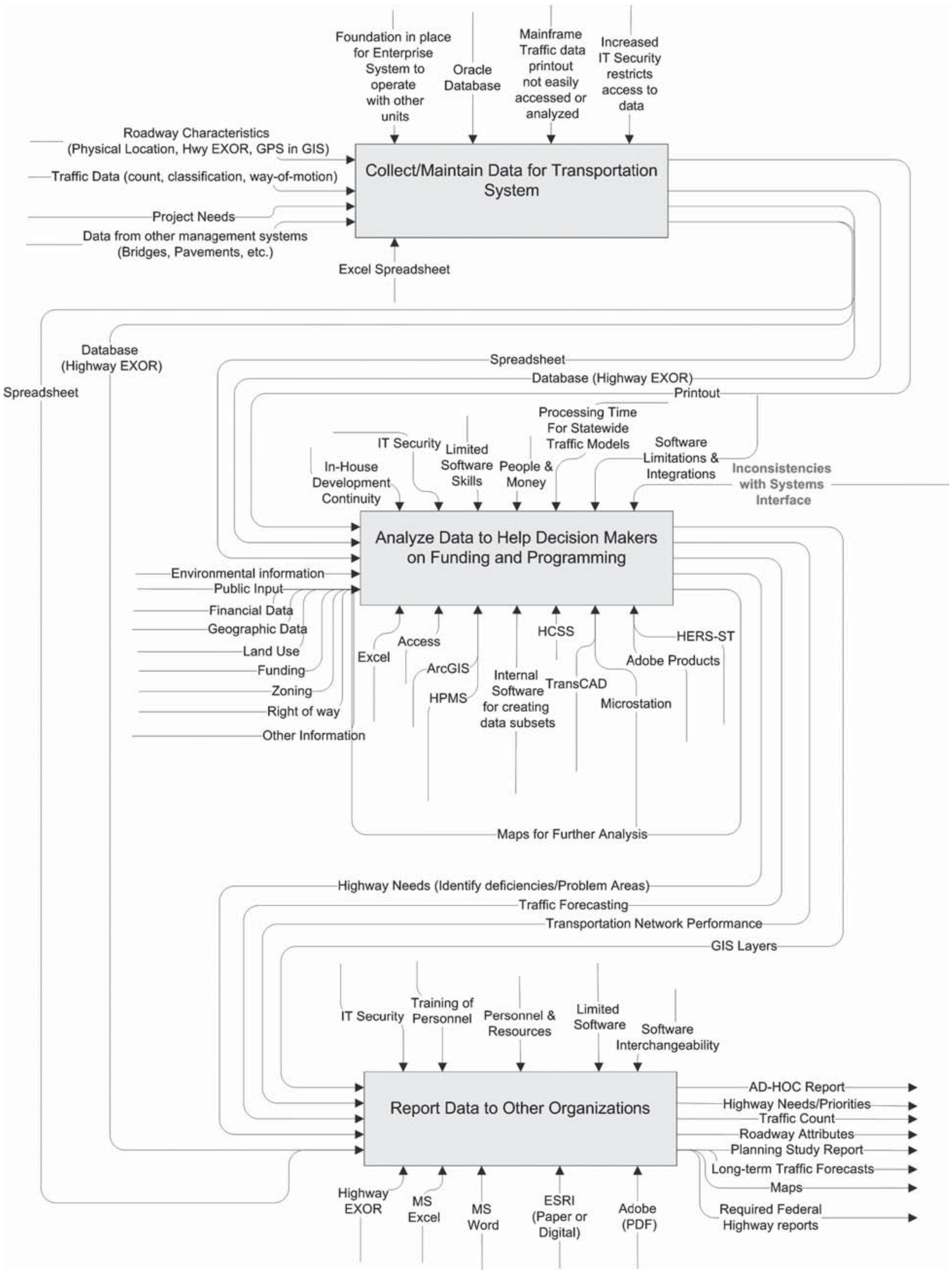


FIGURE 7 KYTC data work-flow diagram for planning functional area.

TABLE 4
SOFTWARE APPLICATIONS AND DATA FORMATS USED BY KYTC PLANNING FUNCTIONAL AREA

| Application | Software Application-Vendor | Data File Formats |
|---|---|---|
| Infrastructure Asset Management—GIS Map Layers | HIS-EXOR Corp.<br>Oracle Highways—Oracle | Proprietary/Open |
| Spreadsheet | Excel—Microsoft | Proprietary |
| Desktop Database | Access—Microsoft | Proprietary |
| GIS | ArcGIS—ESRI | Proprietary |
| File Management | Internal—KYTC | Open |
| Historical Estimating | Bidhistory.com—HCSS | Proprietary |
| CAD | TransCAD—Caliper Corp. | Proprietary |
| CAD | Microstation—Bentley | Open |
| Document Management | Adobe Professional—Adobe | Proprietary |
| Engineering/Economic Analysis | HERS–ST—FHWA | Open |
| Highway Performance Monitoring System | HPMS—FHWA | Proprietary |
| Text Documents | Word—Microsoft | Proprietary |

CHAPTER FOUR

# INFORMATION TECHNOLOGY FOR DESIGN

## FUNCTIONAL AREA DEFINITION

The design functional area receives inputs from the planning function for the purposes of producing the scope of the planned facility and deciding final parameters and elements from the alternatives input. At NYSDOT this includes 3D design models, specifications, and contract documents including bid and proposal documents that are passed forward to the procurement function.

## DESIGN FUNCTION DELIVERABLES

Responses to the survey questionnaire revealed the deliverable types or datasets shown in Table 5 as being received, processed, or sent through the design functional area. Responses are indicated by two numbers: response count followed by percentage of total responses for the functional area.

## ADVANCED PROCESSES

NYSDOT performs a best practice in the design functional area by creating a 3D design model of the project. This practice is efficient as it serves two main purposes that reduce input procedures and efforts internally, externally, and across the project life cycle.

- Internally: The 3D design model is passed to the procurement, construction, and O&M functional areas where design data are extracted for the deliverables in those functional areas, thereby reducing redundant resource input and increasing accuracy within the organization.
- Externally: The 3D design model is shared with the contractor, allowing technology-savvy individuals to perform virtual construction [4D (three dimensions plus construction project scheduling) CAD scheduling and virtual reality constructability review] and 5D (three dimensions plus construction project estimate) CAD estimating, thereby reducing redundant resource input and increasing accuracy within the external project organizations.
- Life cycle: The 3D design model acts as the shell for a 3D design model that can follow the project's life-cycle stages, acting as an information repository by allowing input and extraction of data throughout the project's life.

FDOT performs advanced processes in the design functional area as follows:

- The development of a project compact disc (CD) containing all the design documents and deliverables required for their electronic bid letting process.
- As the CD gets processed between the design and procurement functional areas, their process enables checks for completeness, compliance with statutes and directives, versioning, and QA.

*Case Study #1 NYS DOT*

- *Work-Flow Process Diagram.* Figure 6 (page 14) shows a data work-flow diagram for design functional area.
- *Software Applications Utilized.* Table 6 displays the software applications and data formats extracted from the IDEF0 diagram for NYSDOT design functional area (see Figure 8).
- *Hardware and Networks.* Microsoft Windows 2003 Server networks are utilized.
- *Challenges and Process Adjustments.* The NYSDOT reported the following barriers and challenges to advanced processes implementation:
  - Justification of efficient process change compared with cheaper, but less efficient, processes.
  - Development of functional area culture or mindsets to make efficiency changes, specifically 3D design and modeling.
  - Proprietary file formats that prevent efficient data exchange between software applications, specifically in regard to DTMs.

*Case Study #2 FDOT*

- *Work-Flow Process Diagram.* Figure 9 shows a data work-flow diagram for design functional area.
- *Software Applications Utilized.* Table 7 displays the software applications and data formats extracted from the IDEF0 diagram for FDOT design functional area.
- *Hardware and Networks.* Linux and Microsoft Windows 2003 Server Networks are utilized.
- *Challenges and Process Adjustments.* FDOT reported the following barrier and challenge to advanced processes implementation:
  - State statute required for electronic signature substitute for engineer's plan stamp.

TABLE 5
DATA RECEIVED, PROCESSED/GENERATED, SENT
FROM DOT DESIGN FUNCTIONAL AREAS

| Data Type | Receive | Process/Generate | Send |
|---|---|---|---|
| Survey Boundary | 21–91% | 15–65% | 14–61% |
| Elevation Survey | 22–96% | 17–74% | 14–61% |
| Drawings | 15–65% | 22–96% | 15–65% |
| Supplemental Specs | 18–78% | 21–91% | 15–65% |
| Pay Item Quantities | 17–74% | 23–100% | 18–78% |
| Other Data: | | | |
| Environmental | 1–4% | 1–4% | 1–4% |
| 3D CAD Models | 1–4% | 1–4% | |
| Standard Drawings | 1–4% | 1–4% | 1–4% |
| Environmental Mapping | 1–4% | | |
| Traffic Data | 3–12% | 1–4% | |
| Highway Design Manual | | 1–4% | 1–4% |
| Surface Design | 1–4% | | |
| Subsurface | 1–4% | 1–4% | |
| Hydrologic Design | 1–4% | 1–4% | |
| Plan Preparation Guide | | 1–4% | 1–4% |
| Surface Design | 1–4% | | |
| Bridge Plans | 1–4% | 1–4% | |
| Instructional Bulletins | | 1–4% | 1–4% |
| Qualified Products List | 1–4% | 1–4% | 1–4% |
| Electrical Design | 1–4% | | |
| Landscape Design | 1–4% | | |

TABLE 6
SOFTWARE APPLICATIONS AND DATA FORMATS USED
BY NYSDOT DESIGN FUNCTIONAL AREA

| Application | Software Application—Vendor | Data File Formats |
|---|---|---|
| Design Engineering | InRoads—Bentley | Open/Proprietary |
| Design Graphics | MicroStation—Bentley | Closed/Proprietary |
| Terrain Cross—Sections | GEOPAK—Bentley | Closed/Proprietary |
| Pay Item Quantity Database | Oracle | Open/Proprietary |

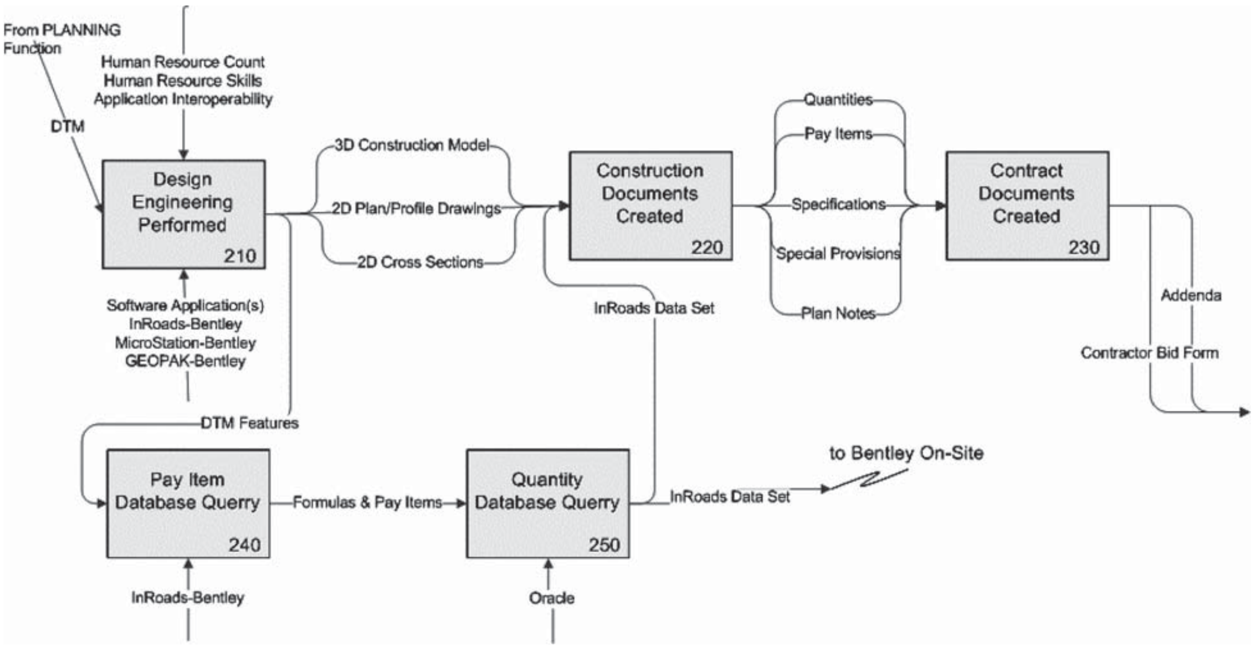


FIGURE 8 NYSDOT data work-flow diagram for design functional area.

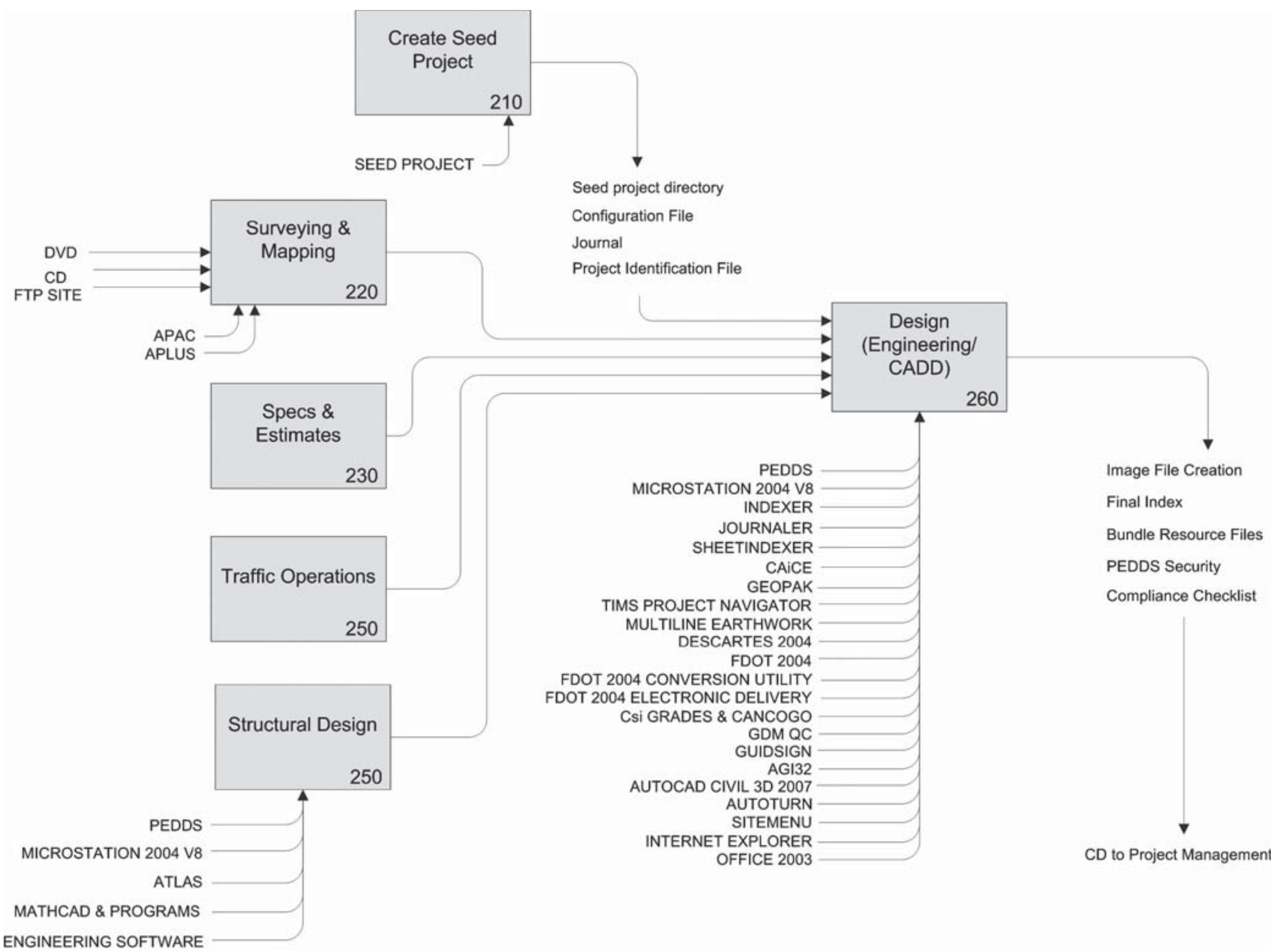


FIGURE 9 FDOT data work-flow diagram for design functional area.

TABLE 7
SOFTWARE APPLICATIONS AND DATA FORMATS USED BY FDOT DESIGN FUNCTIONAL AREA

| Function | Software Application—Vendor | Data Format |
|---|---|---|
| Structural Design/Design Engineering | PEDDS—FDOT | Open |
| Structural Design/Design Engineering | MicroStation—Bentley | Proprietary/Open |
| Structural Design | Atlas | Proprietary/Open |
| Structural Design | MathCad | Proprietary/Open |
| Design Engineering | Indexer | Proprietary/Open |
| Design Engineering | Journaler | Proprietary/Open |
| Design Engineering | SheetIndexer | Proprietary/Open |
| Design Engineering | CAICE | Proprietary/Open |
| Design Engineering | GEOPAK | Proprietary/Open |
| Design Engineering | TIMS—FDOT | Proprietary/Open |
| Design Engineering | MultiLine Earthwork | Proprietary/Open |
| Design Engineering | Descartes | Proprietary/Open |
| Design Engineering | CANCOGO | Proprietary/Open |
| Design Engineering | GDM QC | Proprietary/Open |
| Design Engineering | GUIDSIGN | Proprietary/Open |
| Design Engineering | AGI32 | Proprietary/Open |
| Design Engineering | AutoCAD Civil—Autodesk | Proprietary/Open |
| Design Engineering | AUTOTURN | Proprietary/Open |
| Design Engineering | SiteMenu | Proprietary/Open |
| Design Engineering | Office 2003—Microsoft | Proprietary |

CHAPTER FIVE

# INFORMATION TECHNOLOGY FOR PROCUREMENT

## FUNCTIONAL AREA DEFINITION

The procurement functional area is responsible for advertising and awarding the construction contracts to outside construction contractors, including all documents and processes required by applicable statutory regulations.

## PROCUREMENT FUNCTION DELIVERABLES

Responses to the survey questionnaire revealed the deliverable types or datasets shown in Table 8 as being received, processed, or sent through the procurement functional area. Responses are indicated by two numbers: response count followed by percentage of total responses for the functional area.

## ADVANCED PROCESSES

FDOT performs the following best practice in the procurement functional area:

- Internally: A secured CD is created containing electronic final plans that is authenticated using the Professional's Electronic Data Delivery System (PEDDS) application. The CD is authenticated to contain the final versioning of all drawings and is then reviewed for QA and project compliance.
- Externally: The FDOT Contracts Administration Office adds a proposal form to the Plans & Specs version of the CD and makes copies for delivery to external contractors that bid on the project.
- Life cycle: The CD-ROM is utilized to collect agency data through all stages of the project. See O&M functional area in chapter six.

*Case Study: FDOT*

- *Work-Flow Process Diagram*. Figure 10 shows a data work-flow diagram for a procurement functional area.
- *Software Applications Utilized.* Table 9 displays the software applications and data formats extracted from the IDEF0 diagram for the FDOT procurement functional area.
- *Hardware and Networks.* Linux and Microsoft Windows Servers are utilized.
- *Challenges and Process Adjustments*. The FDOT reported the following barrier and challenge to advanced processes implementation:
  – To deliver electronic drawings (CAD) to contractors, legislative action was required for acceptance of digital signatures to replace physical engineer's stamps on paper drawings (approval of professional engineer).

TABLE 8
DATA RECEIVED, PROCESSED/GENERATED, SENT FROM DOT PROCUREMENT FUNCTIONAL AREAS

| Data Type | Receive | Process/Generate | Send |
|---|---|---|---|
| Bidding Documents | 13–52% | 20–80% | 12–48% |
| Survey | 10–40% | 8–32% | 6–24% |
| Drawings | 11–44% | 14–56% | 8–32% |
| Supplemental Specs | 17–68% | 18–72% | 15–60% |
| Pay Item Quantities | 16–64% | 18–72% | 15–60% |
| Bid Results/Tabs | 15–60% | 21–84% | 18–72% |
| Other Data: | | | |
| Professional Services Procurement | 1–4% | 1–4% | 1–4% |
| Invitation to Bid | | 1–4% | 2–8% |
| Contract Funding | 1–4% | 1–4% | |
| Contractor Bid | 1–4% | 1–4% | |
| Addendums | 1–4% | 1–4% | 1–4% |
| Bid Specifications | 1–4% | 1–4% | |
| Product/Process Quality | | 1–4% | |

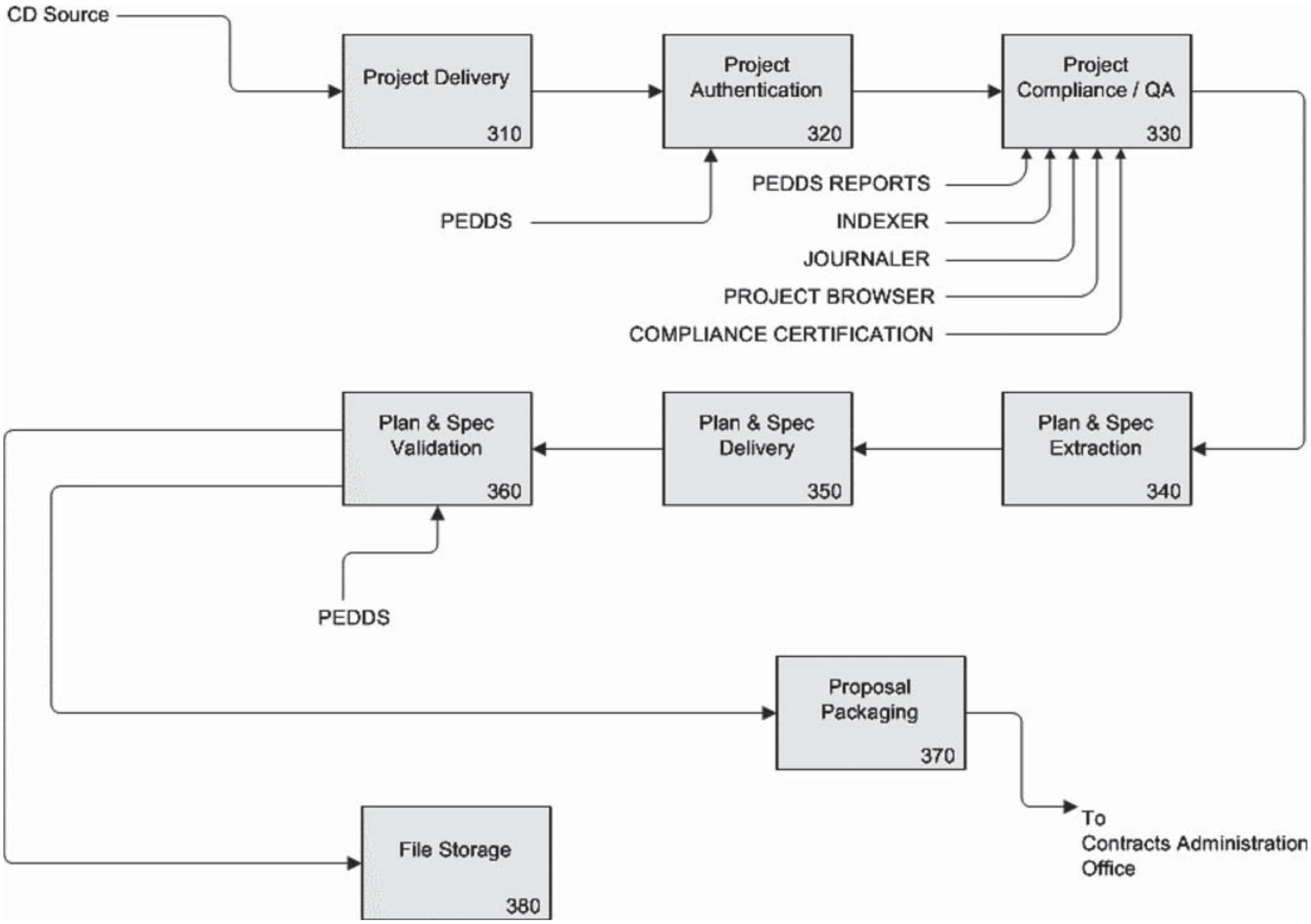


FIGURE 10 FDOT data work-flow diagram for procurement functional area.

TABLE 9
SOFTWARE APPLICATIONS AND DATA FORMATS USED BY FDOT PROCUREMENT FUNCTIONAL AREA

| Application | Software Application—Vendor | Data File Formats |
|---|---|---|
| Project Compliance | PEDDS—FDOT | Proprietary/Open |
| Project Compliance | Indexer | Proprietary/Open |
| Project Compliance | Journaler | Proprietary/Open |

CHAPTER SIX

# INFORMATION TECHNOLOGY FOR CONSTRUCTION

## FUNCTIONAL AREA DEFINITION

The construction functional area is responsible for managing the physical construction of the facility in the field, documenting work progress, monitoring project quality and safety, and processing change orders and contractor payment requests.

## CONSTRUCTION FUNCTION DELIVERABLES

Responses to the survey questionnaire revealed the deliverable types or datasets shown in Table 10 as being received, processed, or sent through the procurement functional area. Responses are indicated by two numbers: response count followed by percentage of total responses for the functional area.

## ADVANCED PROCESSES

KYTC performs the following best practice in the construction functional area:

- Internally: XML is utilized whenever possible for export and import of data between software applications.

FDOT performs the following best practice in the construction functional area:

- Internally: Contracting with IBM Corporation for the set-up of wireless networks on selected jobsites. This gives the on-site FDOT personnel Internet, web-based access to project information on laptops, tablet computers, and personal digital assistants (PDAs).

*Case Study: KYTC*

- *Work-Flow Process Diagram*. Figure 11 shows a data work-flow diagram for a construction functional area.
- *Software Applications Utilized.* Table 11 displays the software applications and data formats extracted from the IDEF0 diagram for the KYTC construction functional area.
- *Hardware and Networks.* Hard-wired Ethernet Internet networks are deployed by the KYTC; wireless Internet networks are deployed by FDOT.
- *Challenges and Process Adjustments.* No major issues reported.

TABLE 10
DATA RECEIVED, PROCESSED/GENERATED, SENT FROM DOT CONSTRUCTION FUNCTIONAL AREAS

| Data Type | Receive | Process/Generate | Send |
|---|---|---|---|
| Daily Diary | 12–46% | 18–69% | 9–35% |
| Certified Payroll | 3–12% | 3–12% | 3–12% |
| QA/Control | 9–35% | 14–54% | 10–38% |
| Work Progress (Quantity) | 16–62% | 20–77% | 18–69% |
| Schedule Progress | 14–54% | 13–50% | 12–46% |
| Meeting Minutes | 15–58% | 15–58% | 16–62% |
| Survey | 14–54% | 16–62% | 13–50% |
| Other Data: | | | |
| Subcontract Submittals | 1–4% | 1–4% | 1–4% |
| Change Orders | 1–4% | 2–8% | 1–4% |
| Engineering Estimates | 1–4% | 1–4% | 1–4% |
| Contract Extensions | 1–4% | | |
| Contractor Payments | | 2–8% | 2–8% |
| Contractor Pay Estimates | 2–8% | 1–4% | 1–4% |
| Contract Documents | 1–4% | 1–4% | 1–4% |
| Material Sampling/Testing | | 1–4% | |
| Standard Specifications | | 1–4% | 1–4% |

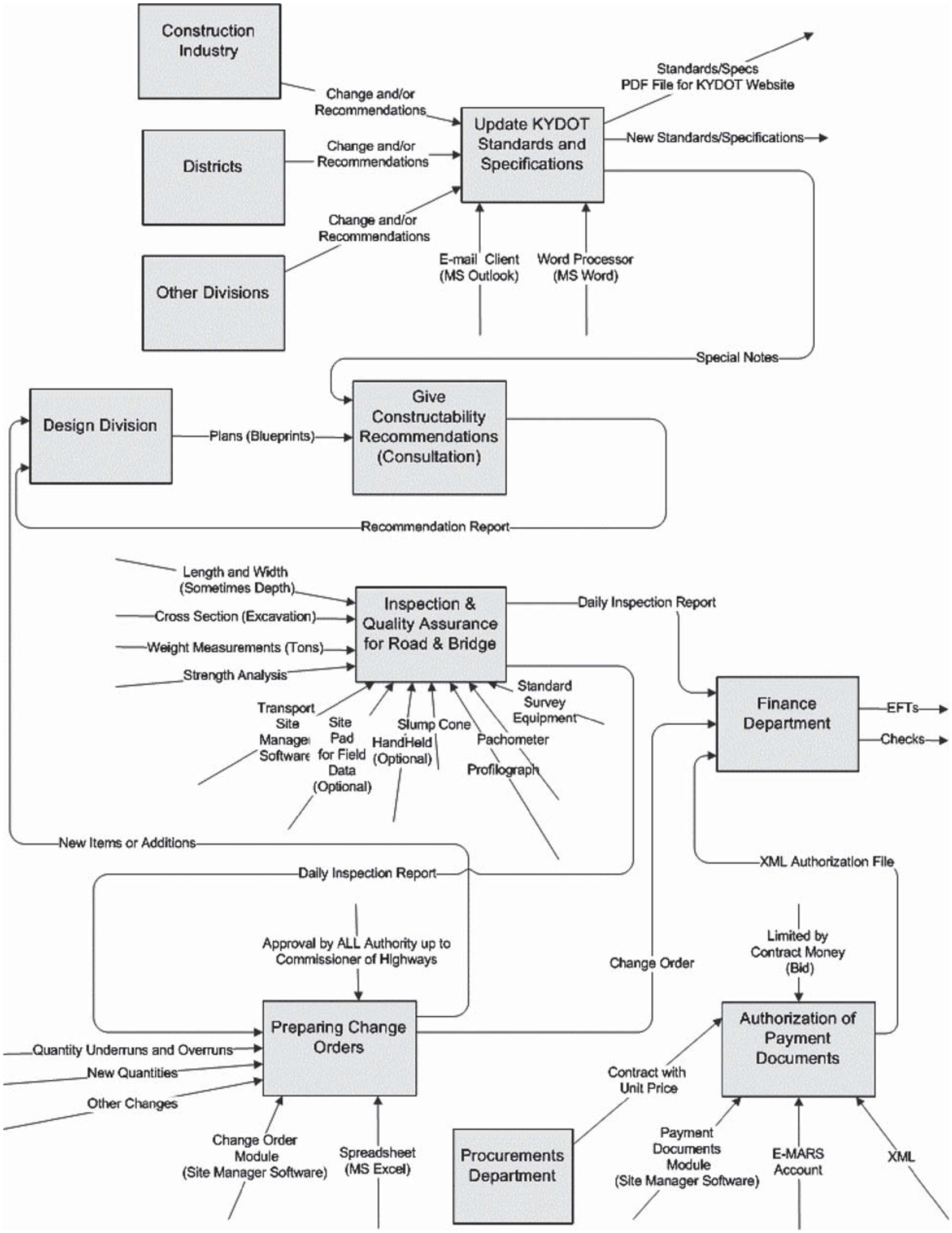


FIGURE 11 KYTC data work-flow diagram for construction functional area.

TABLE 11
SOFTWARE APPLICATIONS AND DATA FORMATS USED BY KYTC CONSTRUCTION FUNCTIONAL AREA

| Function | Software Application—Vendor | Data Format |
|---|---|---|
| E-mail client | Outlook—Microsoft | Closed/Proprietary |
| Word processor | Word—Microsoft | Closed/Proprietary |
| Construction management system | Transport SiteManager—AASHTO | Open/Proprietary |
| Field documentation system | SitePad FieldManager—AASHTO | Open/Proprietary |
| Spreadsheet | Excel—Microsoft | Closed/Proprietary |
| Accounting | eMars—KYTC | |

CHAPTER SEVEN

# INFORMATION TECHNOLOGY FOR OPERATIONS AND MAINTENANCE

## FUNCTIONAL AREA DEFINITION

The O&M functional area is responsible for the management of the built facility after the construction contractor achieves substantial completion of the project. These duties would include maintaining safe readability, signage, striping, and repair.

## OPERATIONS AND MAINTENANCE FUNCTION DELIVERABLES

Responses to the survey questionnaire revealed the deliverable types or datasets shown in Table 12 as being received, processed, or sent through the procurement functional area. Responses are indicated by two numbers: response count followed by percentage of total responses for the functional area.

## ADVANCED PROCESSES

An advanced process performed in the O&M functional area by the KYTC includes:

- Internally: XML is utilized whenever possible for export and import of data between software applications.

TABLE 12
DATA RECEIVED, PROCESSED/GENERATED, SENT FROM DOT OPERATIONS AND MAINTENANCE FUNCTIONAL AREAS

| Data Type | Receive | Process/Generate | Send |
|---|---|---|---|
| Final Survey | 10–45% | 6–27% | 4–18% |
| As-Built Quantities | 11–50% | 7–32% | 8–36% |
| As-Built Drawings | 9–41% | 7–32% | 7–32% |
| Pay Requests | 6–27% | 7–32% | 6–27% |
| EEO Compliance | 4–18% | 4–18% | 4–18% |
| SWP3 Documentation | 4–18% | 4–18% | 3–14% |
| Certified Payroll | 4–18% | 3–14% | 3–14% |
| Contract/Bid Docs | 10–45% | 6–27% | 5–23% |
| Claims | 10–45% | 7–32% | 6–27% |
| Other Data: | | | |
| Contract Completion Acceptance | 1–4% | | |
| Local Agency Payment System | 1–4% | 2–8% | 1–4% |
| Traffic Flow Data | 1–4% | 1–4% | 1–4% |
| Construction Submittals | 1–4% | 1–4% | 1–4% |
| Underground Feature Inventory | | 1–4% | |
| Contract Awards | 1–4% | | |
| Maintenance Activity Reporting | 1–4% | 1–4% | 1–4% |
| Video Data | 1–4% | 1–4% | 1–4% |
| Pavement Condition Survey | | 1–4% | |
| Safety, Signal, Sign | 1–4% | 1–4% | 1–4% |
| Incident | 1–4% | 1–4% | 1–4% |
| Integrated Maintenance Management System | | 1–4% | |
| Bridge and Sign Structure | 1–4% | 1–4% | 1–4% |
| Construction Information | 1–4% | 1–4% | 1–4% |
| Bridge Level of Service | | 1–4% | |
| Road Weather Information | 1–4% | 1–4% | 1–4% |
| Maintenance Program Level Action Plan | | 1–4% | |

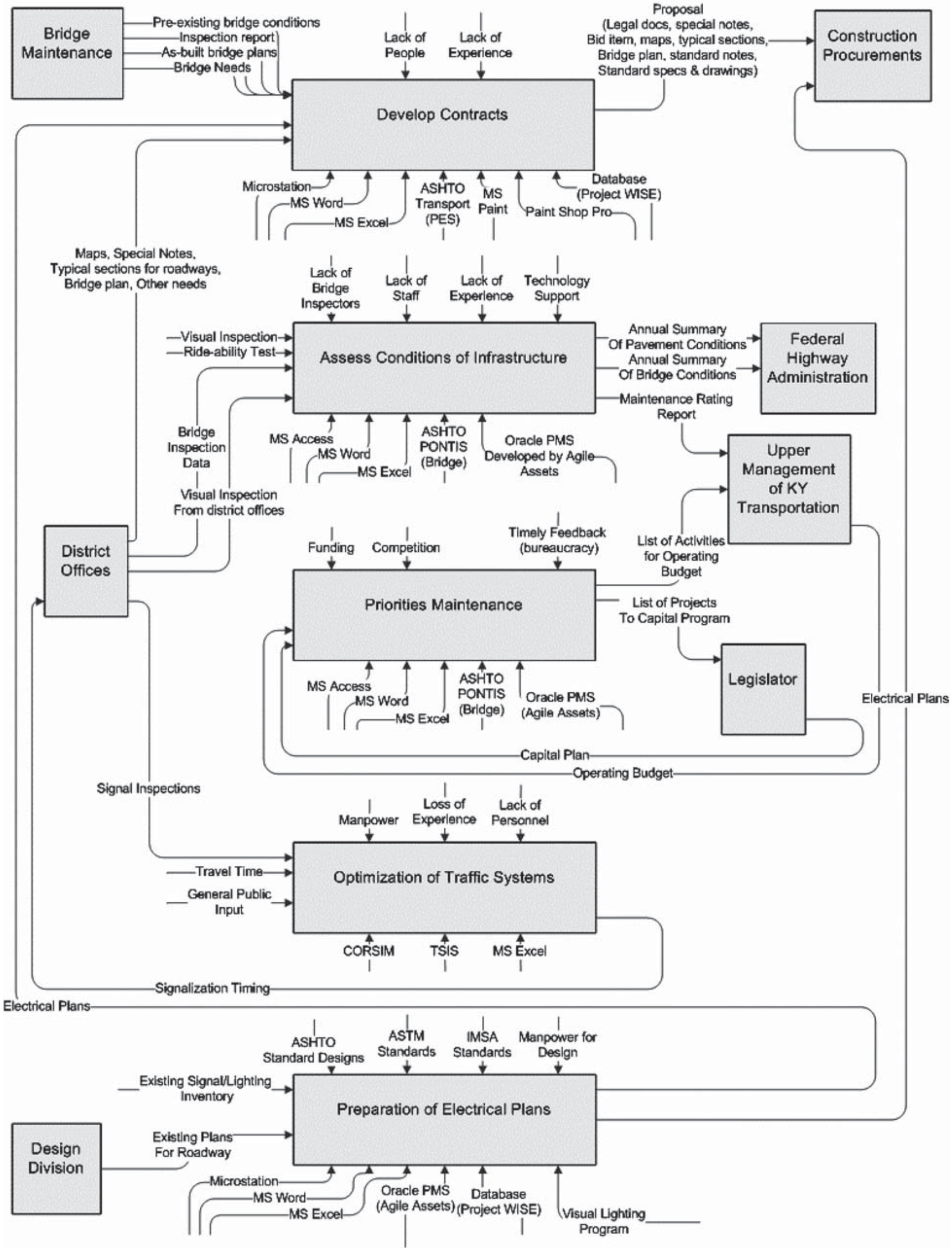


FIGURE 12 KYTC data work-flow diagram for operations and maintenance functional area.

TABLE 13
SOFTWARE APPLICATIONS AND DATA FORMATS USED BY KYTC OPERATIONS AND MAINTENANCE FUNCTIONAL AREA

| Function | Software Application—Vendor | Data Format |
|---|---|---|
| Develop Contracts | Word—Microsoft | Proprietary |
| Develop Contracts | Excel—Microsoft | Proprietary |
| Develop Contracts/Electrical Plans | Microstation—Bentley | Proprietary/Open |
| Develop Contracts | Transport—AASHTO | Proprietary/Open |
| Develop Contracts | ProjectWise—AASHTO | Proprietary/Open |
| Develop Contracts | Paint Shop Pro—Corel | Proprietary |
| Assess Conditions/Priorities Maintenance | Word—Microsoft | Proprietary |
| Assess Conditions/Priorities Maintenance | Excel—Microsoft | Proprietary |
| Assess Conditions/Priorities Maintenance | Access—Microsoft | Proprietary |
| Assess Conditions/Priorities Maintenance | Pontis—AASHTO | Proprietary/Open |
| Assess Conditions/Priorities Maintenance | Oracle PMS—Agile Assets | Proprietary/Open |
| Traffic System Optimization | CORSIM—McTrans/FHWA | Proprietary/Open |
| Traffic System Optimization | TSIS—McTrans/FHWA | Proprietary/Open |
| Traffic System Optimization | Excel—Microsoft | Proprietary |
| Prepare Electrical Plans | Microstation—Bentley | Proprietary/Open |
| Prepare Electrical Plans | Word—Microsoft | Proprietary |
| Prepare Electrical Plans | Excel—Microsoft | Proprietary |
| Prepare Electrical Plans | Oracle PMS—Agile Assets | Proprietary/Open |
| Prepare Electrical Plans | ProjectWise—AASHTO | Proprietary/Open |
| Prepare Electrical Plans | Visual Lighting | Proprietary/Open |

Advanced processes performed in the O&M functional area by FDOT include the following:

- Internally/Life Cycle: The CD-ROM initiated in the procurement stage, initially containing design and bid data, is populated with the following data throughout the project life cycle and contains the following for file storage (archiving) in a District PEDDS database when the project is considered complete:
  - Engineering data files,
  - Graphics design files,
  - Image files,
  - Electronic journal,
  - Project index (XML),
  - QC reports,
  - Compliance certifications,
  - Specifications workbook,
  - PEDDS information,
  - Composite of plans,
  - Sheet index report.

*Case Study: KYTC*

- *Work-Flow Process Diagram*. Figure 12 shows a data work-flow diagram for an O&M functional area.
- *Software Applications Utilized*. Table 13 displays the software applications and data formats extracted from the IDEF0 diagram for the KYTC O&M functional area.
- *Hardware and Networks*. Unix, Linux, and Microsoft Networks are utilized.
- *Challenges and Process Adjustments*. KYTC reported the following barrier and challenge to advanced processes implementation:
  - Lack of appropriate numbers of staff with required technical training and skill sets to utilize multiple software applications, especially with a recent generation of personnel eligible and becoming eligible for retirement.

CHAPTER EIGHT

# INTEGRATED PROCESS MODEL

## INTEGRATED WORK PROCESS FOR PROJECT DELIVERY

The concept of the IPM evolves from all three investigative aspects of the synthesis study (see Figure 13).

1. From the case studies, several of the agencies studied reveal innovative concepts in various functional areas and stages of maturity that can be combined to form a complete project life-cycle model. Most significant are the New York processes that initiate 3D modeling in the planning and design functional areas. This process change, from two-dimensional (2D) survey and design, is also a quickly growing technique in the vertical construction industry segments (commercial, plant/process/manufacturing) known as building information modeling (BIM). To date, however, the BIM concept has not been documented in literature as having functions in the construction, operations, or maintenance life-cycle stages, although one theory is to encapsulate *all* project data within the BIM. FDOT has taken existing, reliable technology (CD-ROM media, digital signatures, etc.) and created a repository and archival mechanism that collects data throughout all the functional areas or life-cycle stages. By melding these two concepts, the IPM is the 3D modeling concept where the model also becomes the vessel of storage, retrieval, sharing, and archiving.
2. From the literature review, it is apparent that technology now exists to realize an IPM or TIM. One of the major barriers to realization is the myriad of differing (proprietary) data formats that must contribute to and retrieve from the TIM. It is not practical that a TIM software application would have the ability (or knowledge of the proprietary trade secret code) to read literally hundreds of different data formats of programs that require access to the model (e.g., CAD, design, scheduling, financial, and document applications). For this reason is it imperative that all software applications accessing the model do so in just a few different data formats. Standardization of data formats guarantees that all contractual parties to the construction contract can communicate with the model. One can think of the TIM as a business office comprised of a dozen or more persons. It takes all of them to successfully run the office. If each person in the office spoke a different language, how efficient would the office be with a dozen translators added to make communication possible? In the same way, the TIM needs a universal language with which all of the participants can communicate digitally. Our literature review revealed several national efforts to standardize the data formats as well as the structure and meaning of the data.
3. From the initial survey, it is apparent that DOTs are in various stages of adopting digital data exchange across functional areas.

## GAPS AND SOLUTIONS

According to our case studies, besides software application interoperability in general, the primary gap in the realization of TIM delivery is that currently the methodology begins to atrophy during and after the construction (project) life-cycle stage. That is to say, there was no evidence of a TIM being utilized beyond the procurement life-cycle stage. This phenomenon was reinforced by the literature review pertaining to BIM project delivery.

Figure 14 displays TIM datasets and their migration and use across functional areas. No extensions of the data in the successive project life-cycle stages or functional areas were found. The exception is FDOT, which uses datasets in file structures burned onto CD-ROMs throughout all of the life-cycle stages; however, this is not the true TIM paradigm.

### Software Interoperability

Software interoperability is currently possible in three main ways at the data file level:

1. Bits of data (binary digits of 0 and 1) can be transferred between files by machine (hardware) interpretation.
2. Data can be converted between differing file structures by means of a common data map, which requires export–import between the software applications (data exchange).
3. All parties to a work process use the same software applications or data file formats, whether standardized or proprietary. This is not typically feasible in most construction delivery scenarios as no proprietary

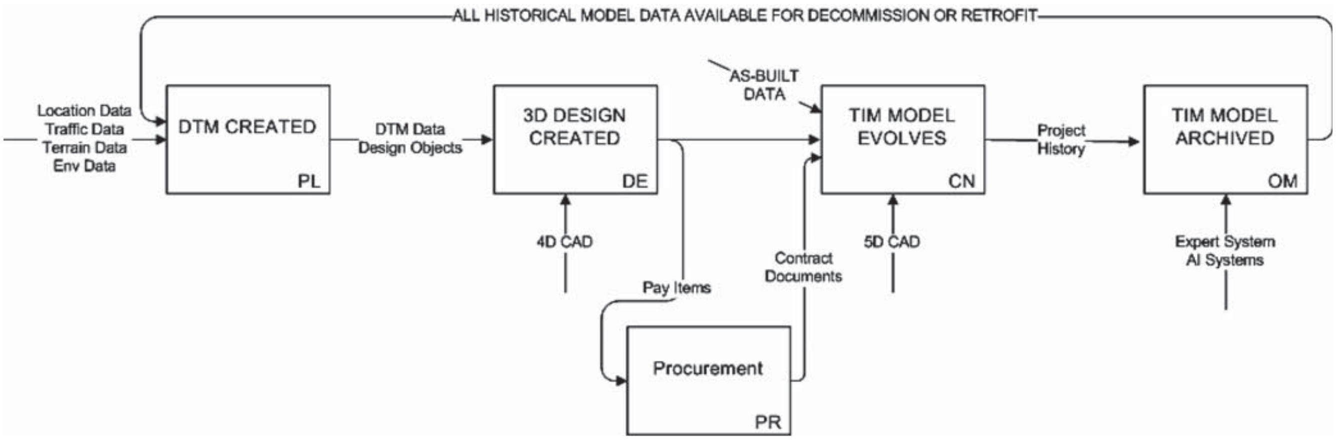


FIGURE 13 Integrated process model.

vendor markets software applications that satisfy all requirements.

Regarding method two, some basics in software application data exchange are useful. Until the last five years or so, data were exchanged between software with differing file formats by exporting from one program and importing into another utilizing a standard file format called ASCII text. This is simply alphanumeric and text characters that could be seen in a text editor (Microsoft Word Pad). Word processors also allow the data to be saved in a text format with a .txt file extension. Data fields in ASCII text format can be separated in several ways using spaces, commas, and other types of separators. For an export–import to occur between two separate software applications, the ASCII text field must be of the same order and type between the two programs.

Figure 15 displays a typical database table consisting of field names ordered from left to right. Each intersection of a field name and record represents a field of data. Data fields consist of text characters of either alphabetic, numeric, or alphanumeric types and a defined number of characters (letters or numbers). In Figure 15, the lower table has some familiar field names and it is easy to imagine the data values inside the fields.

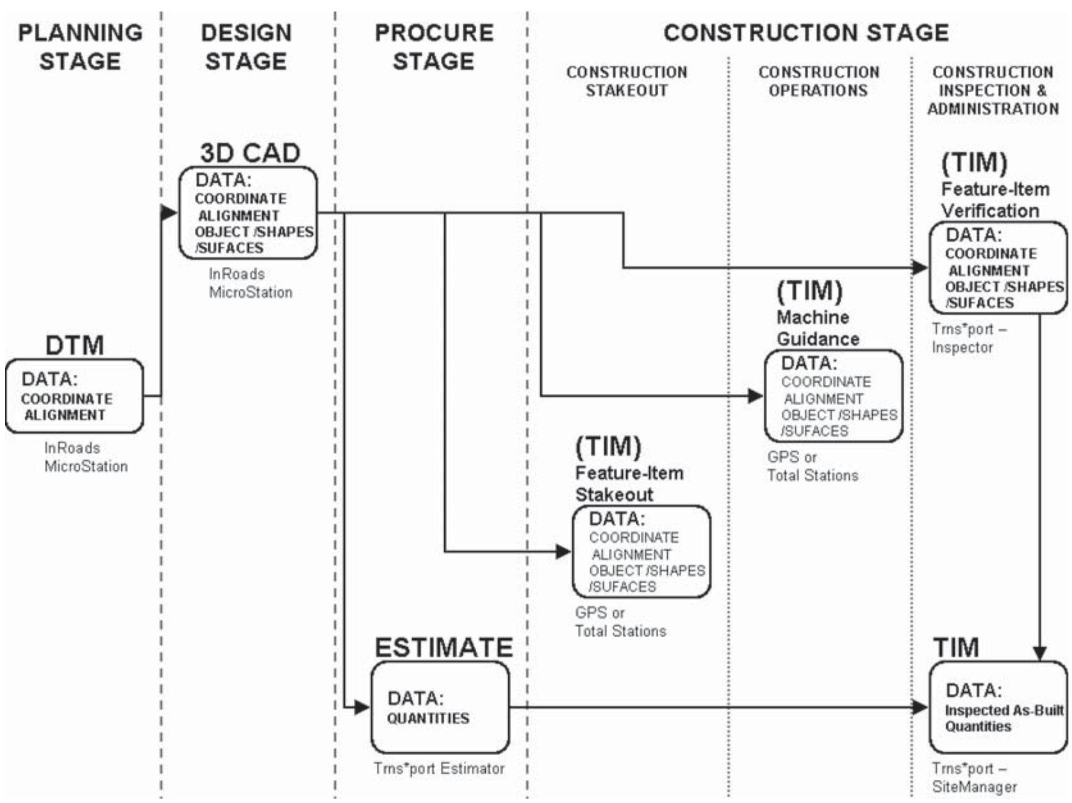


FIGURE 14 TIM model data shown across partial project life-cycle stages (NYSDOT).

| | Field Name 1 | Field Name 2 | Field Name 3 | Field Name 4 | Field Name 5 |
|---|---|---|---|---|---|
| Record 1 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 2 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 3 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 4 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 5 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 6 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 7 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 8 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 9 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 10 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 11 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |
| Record 12 | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype | Field-Datatype |

| | Project No. | Proj. Name | Proj. Type | Contract Value | Contractor |
|---|---|---|---|---|---|
| Record 1 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 2 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 3 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 4 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 5 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 6 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 7 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 8 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 9 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 10 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 11 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 12 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |

FIGURE 15 Database tables.

Software Application 1

| | Project No. | Proj. Name | Proj. Type | Contract Value | Contractor |
|---|---|---|---|---|---|
| Record 1 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 2 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 3 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 4 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 5 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 6 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 7 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 8 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 9 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 10 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 11 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 12 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |

Data Exchange-Mapping

Software Application 2

| | Project No. | Proj. Name | Proj. Type | Contract Value | Contractor |
|---|---|---|---|---|---|
| Record 1 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 2 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 3 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 4 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 5 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 6 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 7 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 8 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 9 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 10 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 11 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |
| Record 12 | AlphaNum * 8 char | Alph* 25 char | Alph* 12 char | Num* 18 char | Alph* 25 char |

FIGURE 16 ASCII text data exchange.

For an ASCII text data transfer to be successful, the fields must be of the same name order and type as shown in Figure 16. If the mapping is not exact, the exchange will not occur correctly, if at all.

Approximately five years ago a data exchange technique using XML came into mainstream use as a more efficient method of exchanging data than ASCII Text. One of the reasons for this popularity is that that the data field size and types must still be matched, but the data order or configuration does not have to match the destination data repository, which is to say that the data can be structured in any manner and still be imported (the data are independent of format and from tabular order). Figure 17 attempts to display the difference of the exchange from Figure 16 and ASCII methodology.

With XML, as long as the two software applications share a common field name or label, and the data fields are structured similarly, exchange will occur. As long as the separate software programs share the same field names (or schema), the data will find their appropriate places in the database on exchange.

The following text structure displays schedule data in XML format as a separate example:


```
<?xml version="1.0" ?>
  <Project xmlns="http://schemas.microsoft.com/project">
  <Name>test.xml</Name>
  <Title>2006 MDOT Spread 2; As Bid 11/25/06</Title>
  <Company>ACME, Inc.</Company>
  <Author>Ricky N. Dyess</Author>
  <CreationDate>1997-10-01T13:42:00</CreationDate>
  <LastSaved>2007-03-31T20:59:00</LastSaved>
  <ScheduleFromStart>1</ScheduleFromStart>
  <StartDate>2007-11-01T07:00:00</StartDate>
  <FinishDate>2008-08-13T17:00:00</FinishDate>
  <FYStartDate>1</FYStartDate>
  <CriticalSlackLimit>0</CriticalSlackLimit>
  <CurrencyDigits>2</CurrencyDigits>
  <CurrencySymbol>$</CurrencySymbol>
  <CurrencySymbolPosition>0</CurrencySymbolPosition>
  <CalendarUID>1</CalendarUID>
  <DefaultStartTime>07:00:00</DefaultStartTime>
  <DefaultFinishTime>17:00:00</DefaultFinishTime>
  <MinutesPerDay>600</MinutesPerDay>
  <MinutesPerWeek>3600</MinutesPerWeek>
  <DaysPerMonth>26</DaysPerMonth>
  <DefaultTaskType>0</DefaultTaskType>
  <DefaultFixedCostAccrual>2</DefaultFixedCostAccrual>
  <DefaultStandardRate>0</DefaultStandardRate>
  <DefaultOvertimeRate>0</DefaultOvertimeRate>
  <DurationFormat>7</DurationFormat>
  <WorkFormat>3</WorkFormat>
  <EditableActualCosts>0</EditableActualCosts>
  <HonorConstraints>0</HonorConstraints>
  <InsertedProjectsLikeSummary>0</InsertedProjectsLikeSummary>
  <MultipleCriticalPaths>0</MultipleCriticalPaths>
  <NewTasksEffortDriven>0</NewTasksEffortDriven>
  <NewTasksEstimated>1</NewTasksEstimated>
  <SplitsInProgressTasks>1</SplitsInProgressTasks>
  <SpreadActualCost>0</SpreadActualCost>
  <SpreadPercentComplete>0</SpreadPercentComplete>
  <TaskUpdatesResource>1</TaskUpdatesResource>
```

The field names or tags are bracketed and encapsulate the data to be exchanged. As long as the separate software applications share the same schema (labels), the data are easily imported and exported between programs with the use of built-in parsers (that read and direct the data to the proper fields).

Hopefully from this demonstration it is possible to envision all transportation software applications sharing a common data scheme, therefore allowing data to be exchanged from any software program utilized in the delivery of construction projects or in any of the agency functional areas.

The largest barrier to experiencing this method of interoperability is convincing industry-segment participants to agree on a standardized (universal) schema, which has been and is being attempted in several industry segments with limited success. NCHRP has funded research for the development of TransXML, an intended universal schema for transportation-related schemas.

The magnitude and detail of datasets required for transportation agency specification requires interpretation of these schemas by differing software applications. Dean Bowman, Director of Research and Development at Bentley Systems, states:

> While quite true that TransXML and other efforts to create a standardized schema are important, it is equally important that a "common interpretation" of this schema be established. This is a much more difficult but vital part of the standardization process. Otherwise, the way one software package development group views a given schema attribute can be quite different than the way another software package developer interprets the same identical schema attribute (D. Bowman, Bentley Systems, personal communication, 2007).

Bowman goes on to state that

> At Bentley, we ran into interpretation issues upon acquiring InRoads, GEOPAK, and MX. Although each product had independently implemented LandXML, the standard offered multiple ways to store "similar" geometry that lead to widely varying interpretations that, in turn, lead to unsatisfactory interoperability results. An extensive and time-consuming project ensued to guarantee that all three Bentley design systems interpreted the LandXML standard in an identical manner.
>
> Refining and documenting a schema to provide sufficient documentation so that implementers can appreciate various schema subtleties actually is more work than creating the schema itself. However, such consistency analyses represent the essence of true standardization so it cannot be ignored (D. Bowman, Bentley Systems, personal communication, 2007).

Software interoperability is defined as the ability of two or more systems or components to exchange information and to use the information that has been exchanged (Teague 2005b). Given the following:

- Software applications store information in their own unique way, optimized to support the application usage scenarios and functions.
- A data map is always required to share or exchange information among applications.
- A database or data repository is an application too, requiring a data mapping to the database or repository just like any other application.
- A typical large company uses several hundred software applications. No single commercial software supplier provides all needed tools.
- Software users apply internally developed software in addition to commercial software.
- Owner companies approach construction and support of capital facilities as a collaborative effort with multiple

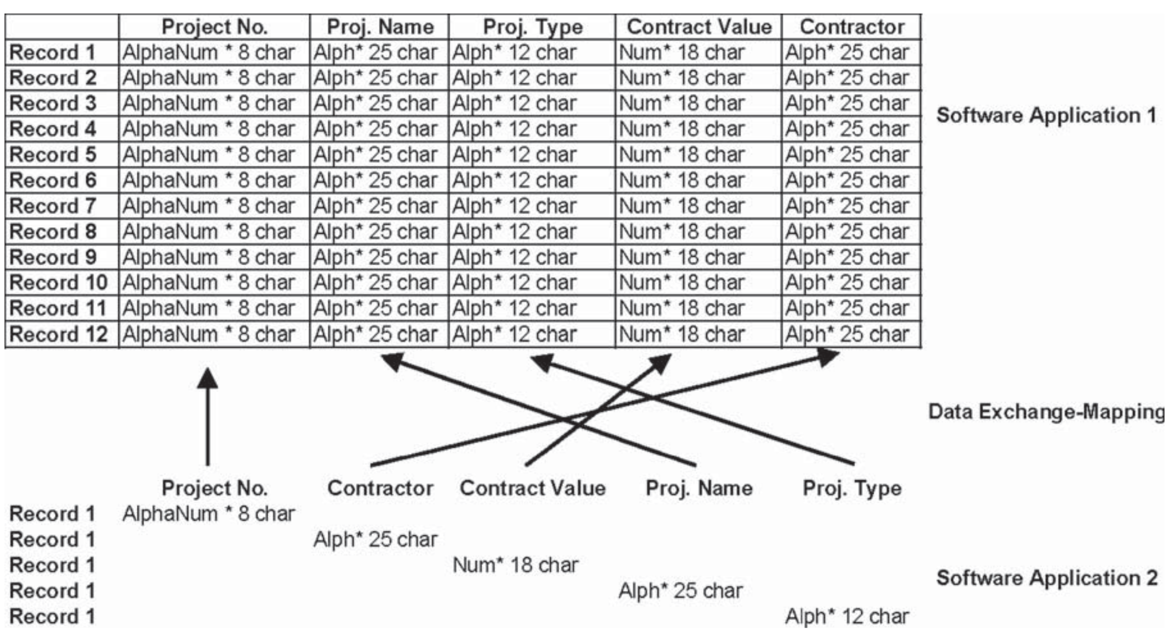


FIGURE 17 Order-independent data exchange possible with XML.

other business entities, including a number of service providers and product suppliers.
- The size of the collaborating business entities that construct and support capital facilities ranges from large, multibillion dollar global corporations with a high level of IT expertise to very small service and product suppliers with a relatively low level of IT expertise.
- Each collaborating business entity has its own preferred tool set of commercial and internal software that, in general, is different from those their collaborators use.

FIATECH concluded that

> . . . there are thousands of application interfaces required to achieve widespread software interoperability, especially when attempting to achieve interoperability across organizational boundaries to support electronic collaboration. Therefore, because of the sheer number of applications to be interfaced, software application mapping is the largest single cost associated with achieving widespread data interoperability (Teague 2005a).

FIATECH continued to explain that the method an organization chooses to achieve interoperability (data mapping methodology) is dependent on whether the organization is attempting interoperability internally or externally. Teague then explains five approaches to achieving interoperability (known today):

1. Human interpretation,
2. Developing internal database integration solutions,
3. Purchasing commercial database integration solutions,
4. Integrating product suites purchased from the same vendor, and
5. Creating software mapping interfaces.

Expanding on number 5, creating software mapping interfaces, two methodologies are contrasted as follows:

1. Point-to-point software maps. In this methodology, datasets are matched between applications (field formats, column order, etc.). The data are then exported from one application for import into another. Each time datasets are migrated from one application to another, the field mapping and column ordering must be restructured and the import/export process performed. This approach becomes inefficient according to Teague, as the number of applications needing to exchange data exceeds five each. This method does not scale well.
2. Consensus-based common industry format software maps. When application interfaces are designed to a common data format, then only one mapping operation needs to be done regardless of the software applications involved. This operation scales linearly and can be successfully accomplished with XML schema. Current XML schema developed for the transportation industry are LandXML and TransXML.

#### Standardization

Although interoperability issues such as data exchange can be remedied in part through the usage of XML, a special type of standardization is required when representing objects in the real world with digital data. When digital 3D models are created, digital objects of a certain type must consistently represent the exact same real-life object in every model.

Several standardization efforts of this type have started including a collaborative effort led by FIATECH to establish a universal platform called Accelerated Deployment of International Standards Organization (ISO) 15926 (ADI). ADI begins by using an established, universal language and knowledge base. It implements the ISO Standard 15926 to integrate project life-cycle information about plant facilities. Using ISO 15926, each part used to build the plant is associated with a unique ID from the Reference Data Library. A generic data model defines how these parts should interact with others. All of this is then integrated into a universal language called Web Ontology Language (OWL) of the World Wide Web Consortium (W3C).

Therefore, using the example of a pipe being connected to a tank, we could say, "This is a TANK. It has ID 'TK-1001'. This is a PIPE. It has ID '50-11015.' 'TK-1001' is connected to '50-11015' with a FLANGED CONNECTION since May 1st, 2007." The words shown in capital letters are resident in the central Reference Data Library. The expressions between them are modeled in the generic data model, and the total is implemented in the OWL language.

This standardizes not only the data exchange between design and construction processes of different companies, but also allows firms maintaining the plant several years down the road to understand how it was built. Even if operators speak different languages, they can access and understand this information, making things much easier for everyone. Indeed, preliminary estimates predict a 30% productivity improvement in the engineering, construction, supply-chain, operations, and maintenance phases of plants that implement interoperability.

An additional benefit of this project is that the Reference Data Library continuously grows with information added by contractors and owners. This work-in-progress Reference Data Library allows users to add information about parts, activities, and processes, and use them immediately. The continuous expansion of the Reference Data Library increases the capacity and promise of this project (Fornes 2007).

Another standardization project, the Industry Foundation Classes (IFC) data model, is a neutral and open specification that is not controlled by a singular vendor or group of vendors. It is an object-oriented file format with a data model developed by the International Alliance for Interoperability (IAI) to facilitate interoperability in the building industry, and is a commonly used format for BIM. The IFC model specification is open and available. Because of its focus on ease of interoperability between software platforms, the Danish government has made the use of IFC format(s) compulsory for publicly aided building projects (*Open Format* 2007).

For software applications to achieve interoperability, consensus must be achieved in the order and classification of data. Webster's *Online Dictionary* defines standard as "something set up and established by authority as a rule for the measure of quantity, weight, extent, value, or quality." The online FIATECH Data Standards Clearing House adds the term consensus standards, "which are a voluntary consensus by various joint industry groups to use/adopt agreed on consensus standards and that may not be a true standard in the sense of being 'established by authority' as the dictionary definition suggests" (Teague 2005a).

Teague lists several key characteristics for comparing and understanding industry efforts:

- Domain: Subject domains addressed by the interoperability standard; that is, industrial facilities versus transportation facilities.
- Traditional Type Versus De Facto Type: Traditional standards efforts refer to those sponsored by an official standards body through an official creation process. De Facto refers to voluntary adoption and usage by consensus of participating member organizations without having gone through rigorous official creation processes.
- Intellectual Property (IP)—Open Source or Proprietary: Refers to ownership of the software code as well as the ability or freedoms to view it and/or modify it.
- File Format: Describes the data's file exchange format.
- Usage-Driven Versus Comprehensive Focus: Refers to interoperability standards developed only for information that multiple organizations agree should be exchanged across organizational boundaries. Comprehensive focus refers to standards completely open and flexible to any data exchange.
- Multiple-Domain or Single-Domain Scope.
- Scalability: A measure of how easily the standard can be utilized by very large, complex organizations.
- Extensible Versus Fixed: Refers to the ability, or not, for two parties to extend the standard for purposes of a particular commercial exchange without having to wait for a full standardization process.
- Exchange or Repository Sharing: Relating to broad scope or focused scope, it is the standard application to application or shared by a central repository (application).
- Exchange File Content: Data must be exchanged with defined data names, data types, and structural relationships.
- Data-Only Contained in the Exchange File: Data that are provided to applications in separate data model definition files.
- Data-Model + data: Employs a data exchange file that includes both the data model and the data.

#### Abstract Domain Versus Partitioned Domain

The abstract domain layered data model approach has been adopted by several standards efforts (e.g., STEP and ISO-15926) to address the need to support multiple domains. This approach meets the characteristics of supporting multiple subject domains, but with an added cost and complexity for application owners who must construct software maps that match up the application domain terminology with abstract data model terminology required by the standard. This requires in-depth knowledge and expertise of both the abstract data model and the domain data model. Unfortunately there are few people who have this combination of expertise.

Ben Nelson, Kansas DOT and Synthesis Panel member, states:

> [O]ne of the great complicating factors of interoperable software is having well-defined metadata of the data that are being exchanged. Processes that are able to move one piece of data from one system to another could have great flaws if the data have different metadata. This is, if the data do not satisfy the characteristics of the receiving system, great harm could be done in the engineering field. This leads back to needing detailed definitions and even a knowledge of the data ontology . . . this need is met by having an universally defined set of objects as discussed. Fortunately, the DOTs, as the paper suggests, have gone a long way in defining objects such as the pay items listed in contracts using AASHTO definitions—as well as design objects contained in the AASHTO design guide (and other guides such as the *Manual of Uniform Traffic Control Devices*). Further, private-sector companies that dominate in this area have made progress in defining objects in enough detail that the objects can be considered the same object in terms of the input and output of the systems in which they are shared (B. Nelson, Kansas DOT, personal communication, 2007).

The partitioned domain approach can accommodate by partitioning the multiple domains into some domains, which are general-purpose and reusable, and other domains, which are very subject-specific. However, both the general-purpose and the subject-specific domains use commonly understood "domain terminology" that applies concrete, commonly understood terminology. For example, units of measurement are a general-purpose domain, but are expressed using commonly understood terminology. For XML-based standards, the use of XML namespaces allows sufficient partitioning of the domain data model to enable multiple disciplines or groups to work independently of each other, while providing a common core set of reusable data models that can be applied across multiple subject domains.

The most important advantage of the partitioned domain approach is that writing application software interface mappings to domain-based applications is easier to match up with domain-based terminology in the standard. Therefore, building software maps is less complicated and less expensive than matching domain terminology to abstract terminology (Teague 2005a).

### Business Practices

Business practices (and mindsets) requiring change or re-engineering appear to be as follows:

- The practice of designing in 3D versus 2D.
- Standardized CAD practices (i.e., defining data layers so participants can easily find objects and data from model to model).
- The practice of involving project stakeholders earlier in the project life cycle. With BIM, the designers and builders collaborate early in the life-cycle process to virtually construct the facility, perform constructability reviews, and solve problems with the model before they occur in physical reality. This hurdle may require creative and innovative solutions to realize the benefits. Whereas TIM would lend itself well to design-build project delivery, the predominate design-bid-build delivery is another story as contractors are used to getting 2D drawings at theoretical 100% design completion.
- Legal issues in which innovative cooperation will be required to solve potential liability issues when sharing and relying on digital data supplied by others. Insurance mechanisms and creative agreements must be put in place for the laws to evolve to this technology. The delivery system does not fit current precedent construction law.

### Human Resources and Skills

Agency human capital resources, the information workers, personnel, and staff involved in the TIM delivery methodology will need to acquire additional skill sets. Architecture, engineering, and construction management colleges and universities in the United States are currently in the process of embedding BIM curriculum into their programs; this should eventually benefit the DOT agencies. As a result of BIM curricula, higher education programs are finding that designers are requiring more construction management skills and that the construction students are required to learn design principles they previously could ignore. This phenomenon will no doubt be also true with professional stakeholders involved in the BIM/TIM delivery methodologies. New skills and knowledge will include:

- Cross discipline knowledge (design-construction);
- New software application training;
- IT skills (data exchange, schema and mapping, hardware and networking); and
- Collaboration, cooperation, and communication skills.

CHAPTER NINE

# CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The most promising business practices and technology discovered as a result of the synthesis study are the concepts of three-dimensional (3D) design and construction models applied toward the delivery of transportation construction projects. The case study involving the New York State Department of Transportation (DOT) proves that DOTs can align their business practice efforts toward the successful creation of 3D models that increase internal efficiencies and assist the contractor externally in the layout and grading of the projects. The review of current literature supports this conclusion with the reports from the last few years concerning the building information modeling (BIM)—the successful and proven project delivery system becoming popular in the vertical construction industry. From the Synthesis' small number of case studies and interviews, we have modified the term to transportation information model (TIM). The TIM concept is produced from the hypothetical creation of our integrated process model (IPM) and the concept of smart jobsites such as the Florida DOT is utilizing where project data are accessed wirelessly on the jobsite from a central data repository. The TIM concept would incorporate the following advantages/efficiencies when it is a mature proof-of-concept:

- Efficiency gains in initial surveying when geographic information system/global positioning system data are developed for 3D digital terrain models (DTMs) using fewer required surveyors and project information archived in adjacent TIM project models.
- Constructability reviews can be conducted both internally and externally with the 3D models that are collaboration efforts between the design and planning functional areas. When other project stakeholders are allowed to contribute data to the model (i.e., vendors and suppliers, consultant designers) and visually observe points of errors and conflicts, problems can be solved within the model before they occur in real physical space. BIM is being used with four-dimensional (4D) computer-aided design (CAD) and virtual reality to define design and constructability problems in the models before ground is ever broken. 4D CAD refers to the incorporation of construction scheduling software applications with the design objects in the 3D model. This combination allows viewing of the time-scaled construction of the project, useful for identifying improper construction sequences and construction crew and equipment spatial conflicts among other things. Virtual reality software applications are being integrated with the 3D models to allow the viewer to experience occupation of the soon-to-be constructed facility. For example, with TIM the viewer could place oneself in a virtual car on the project and therefore experience variables such as traffic control plans, nighttime lighting, the sequences and phases of traffic maintenance operations, and driver line-of-sight issues. These processes are also being termed "virtual design and construction" and there are proven case studies of their value in the vertical industry segments.
- Central repository for complete project life-cycle information. If TIM is to develop like BIM, the 3D project models serve as containment vessels for shared project information among the project stakeholders and participants. As with the CD-ROM concept used by FDOT, the TIM file would be the digital repository of all project data from all of the functional areas/project life-cycle stages. Unlike the Florida model, the TIM file itself may be stored (temporarily) on a CD-ROM, but its contents would not be file folder structures, but rather structured data schemas tied to design objects.
- Reduction of redundant data entry. When all contract participants can access their digital data electronically and through networks, data on paper forms no longer have to be re-keyed by humans into software applications.
- Creation of wireless networked jobsites or smart jobsites. Wireless networks enable the remote retrieval of central repository project data in real time on the jobsite. The corollary is true as well; as-built data that are created on the jobsite can be easily incorporated and stored in the central repository. Wireless networks on the project site allow for the use of handheld computers (more ergonomic than laptops in the field), the use of radio frequency identification (RFID) chips (for materials management and quality control in situ testing), and web-based video cameras (for documentation, validation, and schedule confirmation), all of which are coordinated through a project network.
- DOT software development model is becoming more open. Open source software was briefly mentioned earlier in the synthesis. An entire operating system was developed utilizing the Internet network and volunteer programmers. The program (Linux) became mature in the early 1990s and today powers most of the Internet on servers. The licensing that enables this type of development is unique and specific, and to date has not created software applications for domain-specific applications.

The two primary software development systems for DOTs are:

1. Bentley Systems, Inc., a private corporation that produces transportation-specific software applications to DOTs for license fees.
2. AASHTO*Ware is a development and licensing agreement between a majority of the DOTs and AASHTO. Through development committees comprised of DOT personnel, AASHTO receives guidance from committee members regarding features desired in software applications that they license for fee to the agencies. The software development is contracted to a third-party vendor by AASHTO. The study revealed that some of the applications are customizable to differing DOT work business processes. Additionally, some licensing agreements provide the application source code to the DOT licensee (for making changes and functional alterations).

- The DOTs are increasingly seeking enterprise architectures from their software applications. Enterprise resource planning (ERP) systems integrate (or attempt to integrate) all data and processes of an organization into a unified system. A typical ERP system will use multiple components of computer software and hardware to achieve the integration. A key ingredient of most ERP systems is the use of a unified database to store data for the various system modules. The graphic user interface of such systems is typically a web browser. Currently, the ERP systems are split between the administrative/financial functions and the construction functions of the DOT agencies. An ERP system integrated with a TIM delivery system might be the ideal scenario.

The DOT case studies have validated that the 3D modeling concept is mature enough to deliver today, and that at least some agencies are enabling changes in their business processes and functional area mindsets to accommodate this efficient technology for transportation construction project delivery.

Based on the case studies and the literature review, there is a gap between TIM concepts that are being conducted currently and those of the entire IPM. Although further DOT case studies may discover more mature TIM concept developments, this study's limited view, and that of the BIM literature as well, reveals that the 3D model concept is only being fully utilized in the initial stages of the project life cycle. In our case, the TIM model is developed maturely through the design stage, and from there has limited presence in the procurement, construction, and maintenance stages. Therefore, the challenges of using TIM through all stages of the project life cycle become as follows:

- How will as-built data be added and stored in the 3D model? What standardized fields in which database and of which file type should the construction as-built data be received and retrieved by the model? The monolithic CAD object ultimately must somehow be transformed into a more granular and robust form amendable to representing the individual work tasks that comprise estimates and detailed schedules.
- Should data be stored within a single or a series of connected TIM files?
- Should *all* project data be stored in the TIM? Contractors currently allow, and DOTs currently publish, contractor bid prices, work progress quantities, and schedule information. Will they now allow as-built cost data to be captured by the TIM and, if yes, who should have access to that non-public data? It would appear that digital rights management practices would become a part of mature TIM delivery business processes. However, some believe that digital rights management has the potential to reduce efficiency and acts against the sharing and collaboration aspects of the delivery system.
- Who will own the TIM project? Intellectual property rights to the model data will have to be defined.
- Digital data interoperability techniques must be embraced by all project stakeholders. The transportation construction segment urgently needs to define its data dictionary (ontological), schema (industrial foundation classes?), and digital transfer (TransXML?) mechanisms. Standardization of dataset characteristics and attributes is essential for enabling interoperability.
- Standardization may be a less cumbersome effort in transportation compared with the other construction industry segments because many of the DOTs have standardized drawings, specifications, pay items, etc., on AASHTO *Green Book* standards.
- Another barrier to the concept of TIM delivery may be the software application production time required to match software application functionality to changes in DOT business processes.
- TIM project delivery will require agency personnel trained and proficient in design, information technology skills, collaboration, and construction administrative work-flow processes among others.

Based on the preliminary findings in this synthesis study, areas of further and extended research could include:

- For standardization efficiency to occur in TIM project delivery, transportation design objects in CAD must be defined (named) and diagrammed with meaning. Points, shapes, and objects in a CAD 3D drawing must represent real entities in the real world. Unless redefinition is to be performed anew with each new project model, standard hierarchies and ontologies need definition for successive model iterations and model combinations.
- Research regarding the gap between monolithic CAD objects that designers produce and the granular, work-task oriented world that contractors operate. Any transportation object diagramming effort that does not consider an end product expressed in such contractor

terms and subsequent downstream maintenance will not gain significant traction and may end up being merely an academic exercise. This gap can be bridged; however, considerable research as well as practical trial and error is required.

- There could be development of functional area policies and procedures for integration of TIM delivery. This study could extend the IDEF diagramming methodology to develop best practice workflows and assign functional role responsibilities as well as skills and knowledge requirements to create an outline for job descriptions and policies and procedures manuals.
- There could be a comparison of DOT organizational design to match TIM development and delivery processes. How does the implementation of TIM delivery affect the existing organizational structures of transportation agencies? Are there redundant processes and organizational structure that could be modernized and made more efficient? What are the new required training, skills, and knowledge required of DOT information workers in TIM delivery?
- Until mature schemas and ontologies become prevalent and standard, a series of high-level object definitions and attributes may spur the development of the TIM delivery methodology. This might be a starting place for a global transportation or industrial segment-wide terminology that others can build on in the future, thus not delaying technical and process advancements in TIM. The work would be broad enough to be funded in a single research project.
- The legal ramifications of TIM delivery must be explored to find balance between the collaboration and sharing of data requirements in TIM delivery and protection of the intellectual property created by individual stakeholders attributed to the model. Areas to explore could include:
  - Quantifying data sharing/openness versus digital rights management;
  - Developing a digital communication specification governing the use of model data among the stakeholders;
  - Customizing intellectual property licensing practices similar to those being created by the Creative Commons Corporation that address the balance between full copyrights and public domain;
  - Exploring liability issues regarding dependence on digital data; and
  - Developing existing specification reviews and prototypes, if required, incorporating these bulleted features.

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# GLOSSARY OF TERMS, ABBREVIATIONS, AND ACRONYMS

2D: Involving two dimensions, *x*, *y* (length, width).

3D: Involving three dimensions, *x*, *y*, *z* (length, width, depth).

4D: Involving 3D model plus construction project scheduling.

5D: Involving 3D model plus construction project estimate.

6D: Involving 3D model plus work progress data (as-built).

Consultant contract selection process: Flowchart mechanism explaining the contract selection process.

CORS (Continuously Operating Reference Stations): Network of global positioning system (GPS) carrier phase and code range measurements in support of 3D positioning activities throughout the United States and its territories.

Datasets: Collections of related digital data used in a Transportation Information Model (TIM).

DOT: Department of transportation.

DTM: Digital terrain model.

eMARS (Enhanced Management Administrative Accounting Reporting System): Software application created and utilized by the Kentucky Transportation Cabinet.

Field contacts: Flowchart explaining all the departments of a construction firm.

GIS: Geographical information system.

GPS: Geographical positioning system.

GUI (graphical user interface): Computer screen used to navigate through and control software applications.

IDEF0 (Integrated Definition 0): Work process flowcharting method.

Metadata: Descriptive data about sets of data, used to facilitate the understanding, use, and management of the data.

Ontology: Data model that represents a set of concepts within a domain and the relationships between those concepts. It is used to reason about the objects within that domain.

PEDDS (Professional's Electronic Data Delivery System): Software application developed by Florida DOT and used to sign and seal engineering documents stored electronically.

Schema: A schematic diagram, typically hierarchical, which represent the elements or attributes of a system.

Smart jobsite: Construction sites enabled with wireless networked hardware and software so as to have real-time access and contribution to TIM data.

TIM (Transportation Information Model): A multidimensional model of a specific transportation project information that encapsulates, shares, and archives information throughout the project life cycle.

TIMS (Technical Information Management System): Document management system developed by TIMS3 used by Florida DOT.

XML (Extensible Markup Language) Schema: A way to define the structure, content and, to some extent, the semantics of XML documents.

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Quantity commands are used to store and manage pay item information, quantity measurement formulas, and convert geometric measurements of an InRoads DTM feature to a quantity.

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Topics covered include standards and conventions (e.g., developing comprehensive standards and conventions for all engineering content, taking full advantage of latest software capabilities) and resources (e.g., developing and managing engineering resources for all applications).

Annulis, H.M., C. Gaudet, and J.C. Carr, *Opportunities for Change: The Geospatial Workforce Readiness Scorecard*, 2005.

Workforce readiness refers to the ability of a company to have the necessary institutional and managerial components to adapt to new workforce needs. For the geospatial industry, barriers and success factors related to workforce readiness are critically important, given the shortage of qualified geospatial employees within the industry. Using the research methodology from Jim Collins' bestseller *Good to Great*, the University of Southern Mississippi's Workplace Learning and Performance Center conducted a workforce readiness study to identify the barriers and success factors for workforce development for geospatial organizations. The results of this study outline some of the criteria necessary for successful change readiness and have led to the development of the Geospatial Workforce Readiness Scorecard.

Barbara, D., *Mobile Computing and Databases—A Survey*, 1999.

The emergence of powerful portable computers, along with advances in wireless communication technologies, has made mobile computing a reality. Among the applications that are finding their way to the market of mobile computing—those that involve data management hold a prominent position. In the past few years, there has been a tremendous surge of research in the area of data management in mobile computing. This research has produced interesting results in areas such as data dissemination over limited bandwidth channels, location-dependent querying of data, and advanced interfaces for mobile computers. This paper is an effort to survey these techniques and to classify this research in a few broad areas.

Barfield, W. and T.A. Dingus, *Human Factors in Intelligent Transportation Systems* [Online]. Available: http://www.erlbaum.com/ME2/dirmod.asp?sid=28807ECF50FE49F0837125BE640E681F&nm=Books&type=eCommerce&mod=CommerceProductCatalog&mid=CD22EA0F118949C09A932248C040F650&tier=3&id=2EA90C9131F54FEF93A4C13A44F2B7FD&itemid=0-8058-1434-5 [accessed Feb. 27, 2007].

The Intelligent Transportation System (ITS) Program is a cooperative effort by government, private industry, and academia to apply advanced technology to the task of resolving the problems of surface transportation. The objective is to improve travel efficiency and mobility, enhance safety, conserve energy, provide economic benefits, and protect the environment. The current demand for mobility has exceeded the available capacity of the roadway system. Because the highway system cannot be expanded, except in minor ways, the available capacity must be used more efficiently to handle the increased demand. ITS applies advanced information processing, communication, sensing, and computer control technologies to the problems of surface transportation. Considerable research and development efforts will be required to produce these new technologies and to convert technologies developed in the defense and space programs to solve surface transportation problems.

Bärthel, F. and J. Woxenius, "Developing Intermodal Transport for Small Flows over Short Distances," *Transportation Planning and Technology,* Vol. 27, No. 5, 2005, pp. 403–424.

The purpose of this paper is to compare the capabilities of conventional European intermodal transport, with special reference to the competitiveness in markets with small flows over short distances, and to explore innovative concepts. Using a technological systems approach, key functions are identified as being the inducement and blocking mechanisms that affect the development and diffusion path of these small flows over short distances (SFSD) system, providing a tool for empirical delineation of the system. These concepts are illustrated and analyzed through a case study of the Swedish development project Light-combi.

Baysden, C., "State Paid $152.6M More Than Contracted Amount for Roadwork," *Triangle Business Journal*, Dec. 17, 2004.

Raleigh road construction projects completed by contractors for the North Carolina DOT over the past five years cost taxpayers $152.6 million more than the amount of the winning bids.

Bebee, B.R., G.A. Mack, and I. Shafi, *Distributed Metadata Objects Using RDF* [Online]. Available: http://csdl.computer.org/dl/proceedings/wetice/1999/0365/00/03650325.pdf.

This presents RDF representation of distributed Metadata. In the context of information resources, metadata are data about resources. They describe the properties and attributes of an information resource. Operations on the metadata can be as important as operations on the resource content itself. The experimental application showed that a RDF representation is suitable for metadata management. All of the information of the C++ metadata object accessible by means of the CORBA interface was defined within the RDF representation.

Begley, E.F., M.E. Palmer, and K.A. Reed, *Semantic Mapping Between IAI ifcXML and FIATECH AEX Models for Centrifugal Pumps*, National Institute of Standards and Technology, Gaithersburg, Md., 2005.

This report describes a semantic mapping between two extensible markup language (XML) specifications describing a single type of equipment that is used in heating, ventilation, air conditioning, refrigeration (HVAC/R) and other types of systems (e.g., the centrifugal pump).

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This document is a Committee Specification of the Emergency Management Technical Committee. The Common Alerting Protocol (CAP) provides an open, non-proprietary digital message format for all types of alerts and notifications. Key benefits of CAP will include reduction of costs and operational complexity by eliminating the need for multiple custom software interfaces to the many warning sources and dissemination systems involved in all-hazard warning. An international working group of more than 130 emergency managers and information technology and telecommunications experts convened in 2001 and adopted the specific recommendations of the National Science and Technology Council report as a point of departure for the design of a CAP.

Boyd, A., J. Caton, A. Singleton, P. Bromley, and C. Yorks, *TCRP Report 86: Transportation Security Vol. 8: Continuity of Operations Planning Guidelines for Transportation Agencies*, Transportation Research Board, National Research Council, Washington, D.C., 2005, 86 pp.

The project that is the subject of this report was a part of the TCRP study conducted by TRB with the approval of the Governing Board of the NRC. Such approval reflects the Governing Board's judgment that the project concerned was appropriate with respect to both the purposes and resources of the NRC.

Brown, C., P. Balepur, and P.L. Mokhtarian, "Communication Chains: A Methodology for Assessing the Effects of the Internet on Communication and Travel," *Journal of Urban Technology*, Vol. 12, No. 1, 2005, pp. 71–98.

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Captaris, Inc. (NASDAQ: CAPA), a leading provider of Business Information Delivery solutions, announced on April 18, 2005, that the South Carolina DOT Procurement Division has deployed Captaris Workflow to automate its procurement system and help reach its goal to become a paperless operation.

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The event-driven, or notification-based, interaction pattern is a commonly used pattern for inter-object communications. Examples exist in many domains; for example, in publish/subscribe systems provided by Message Oriented Middleware vendors, or in system and device management domains. This notification pattern is increasingly being used in a web services context.

Cheng, J. and K.H. Law, *Using Process Specification Language for Project Information Exchange* [Online]. Available: http://www.mel.nist.gov/msidlibrary/doc/psl_pie.pdf.

There are many project scheduling and management programs employed in the construction industry. Standards-based translation is one way to achieve interoperability. This study evaluates the applicability of the Process Specification Language (PSL) for exchanging project information among different applications. PSL has been initiated by the National Institute of Standards and Technology (NIST) and is emerging as a standard exchange language for process information in the manufacturing industry. In this paper, they explore how PSL can be extended for exchanging project information for construction applications.

Cheng, J., M. Gruninger, R.D. Sriram, and K.H. Law, *Process Specification Language for Project Scheduling Information Exchange*, 2003.

This paper is organized as follows: Section 2 briefly introduces PSL and discusses the motivation and the major components of PSL. Mapping the concepts between PSL and project management applications is discussed in Section 3. Section 4 describes the parser and the wrappers developed for the exchange of project scheduling information using PSL. Section 5 discusses the potential use of PSL for consistency checking using a logic-based reasoning tool. Examples on information exchange and consistency checking are given in Section 6 to demonstrate the current prototype environment. Finally, Section 7 summarizes the results described in this paper.

Cheng, J. and K.H. Law, *Using Process Specification Language for Project Information Exchange*, Civil and Environmental Engineering Department, Stanford University, Stanford, Calif.

This study evaluates the applicability of the PSL for exchanging project information among different applications. PSL has been initiated by NIST and is emerging as a standard exchange language for process information in the manufacturing industry. In this paper, they explore how PSL can be extended for exchanging project information for construction applications.

Cheng, J., M. Gruninger, R.D. Sriram, and K.H. Law, *Process Specification Language for Project Scheduling Information Exchange*, (4), 2003 [Online]. Available: http://www.mel.nist.gov/msidlibrary/doc/psl_pie.pdf.

Many project scheduling and management software systems are being employed in the construction industry. Standards-based translation is one way to achieve interoperability. This study discusses the applicability of the PSL for exchanging project scheduling information among different applications. PSL was initiated by NIST and is emerging as a standard exchange language for process information in the manufacturing industry. This paper explores how PSL can be used for exchanging project scheduling information among software programs in project management. Furthermore, it investigates how PSL could be utilized to reason about potential conflicts and to perform consistency checking on project scheduling information.

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fleet, private-sector motor carriers, and the U.S. military. This report may be used by senior managers, operations managers, materials managers, asset managers, inventory professionals, and procurement officers.

Chisholm, G., *E-Transit: Electronic Business Strategies for Public Transportation. Vol. 2: Application Service Provider Implementation Guidelines*, Mitretek Systems and Transportation Research Board, Washington, D.C., 2002.

*Application Service Provider Implementation Guidelines* presents the results of an investigation into the use of application service providers (ASPs) and thin client computing technologies by transit agencies. The characteristics and market position of ASPs were investigated, and the strengths and weaknesses of this computing service model were identified. A similar investigation of thin client computing was conducted and reported in this volume. This report may be used by senior managers, operations managers, maintenance managers, customer service managers, and schedulers.

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This document describes the behavior and operational parameters required of all UDDI Node Operators.

Clëment, L., *UDDI Version 2.03 Replication Specification*, 2002 [Online]. Available: http://uddi.org/pubs/Replication-V2.03-Published-20020719.htm.

This document describes the data replication process and programmatic interface required to achieve complete data replication between UDDI Operators.

Clëment, L., *Trns-port Module Support Status*, 2006.

The Warranty Reporting Period end dates shown earlier do not apply to errors in previously working functionality. Beginning with the June 2005 releases, errors in previously working functionality (except those resulting from technology upgrades) are warranted for as long as the release is supported, up to a maximum of 24 months.

Clëment, L., *Trns-port Transportation Software Management Solution*, American Association of State Highway and Transportation Officials, Gainesville, Fla., 2006.

The client/server Trns-port modules have a multitiered architecture. Each module uses one or more types of server that can be deployed in many different configurations. There are performance and server availability factors that should be considered when planning an agency's server configuration. This section describes the server types, server requirements, configuration options, and example configurations.

Clëment, L., *Introduction to Next Generation Trns-port and Agile Methodology*, 2007.

The priorities give the Information Technology team an obtainable goal for each sprint. The result is a better, higher-quality solution. The agile methodology is an ongoing part of the future maintenance and enhancement of Trns-port products, and as such should enhance future testing and development to meet the needs of the customers.

Clëment, L., *Next Generation Trns-port Preconstruction Progress*, 2007.

Clëment, L., *Trns-port Platform Component Status by Year*, 2007.

*Committee Research Problem Statements* [Online]. Available: http://gulliver.trb.org/committees/rps2005/AFB30.pdf.

An important function of the TRB is to stimulate research that addresses problems facing the transportation community. In support of this function, TRB technical committees identify problems and develop and disseminate research problem statements for use by practitioners, researchers, and others.

"Connecting Surveyors, Designers, Inspectors, and Contractors," *BE Magazine*.

For the New York State Department of Transportation (NYSDOT), the transition to Bentley's 3D methodology not only represented a milestone in design/engineering automation, but also led to a complete reevaluation of the process NYSDOT had been using to create project data—from 2D drawing production to 3D feature-based modeling.

Conroy, P., *Institutional, Organizational and Market Aspects of Successful ITS Deployment: A Case Study Analysis,* Institute of Transportation Studies, University of California, Berkeley, 2003.

This research continues a previous study to explore key aspects of successful intelligent transportation systems (ITS) deployment within existing institutional, organizational, and market environments. The researcher developed three additional case studies of successful ITS deployment in the United States and Europe, and revisited one case from the previous work. Results from literature searches and surveys were analyzed, and findings on institutional, organizational, and market factors are presented.

Conroy, P., H. Benouar, and J.-L. Ygnace, *ITS Deployment: Global Thinking and Local Action—A Case Study*, University of California Transportation Center, Berkeley, 2003.

This paper explores institutional and organizational factors related to deployment of ITS. The researchers conducted

a comprehensive Internet/literature search on the status of ITS programs in Europe and the United States, interviewed principals involved in ITS deployment both at the policy and project levels and from the public and private sectors, and developed four case studies of successful ITS deployment. Results from the Internet/literature search and responses from the survey and interviews were analyzed to identify critical institutional and organizational factors for successful deployment and operation of ITS systems and services. The methodology allowed for both a top-down (programs and policies) and bottom-up (project experiences) review and analysis.

Cruikshank, D., *Web CGM 2.0,* 2005 [Online]. Available: http://www.oasisopen.org/committees/download.php/15701/WebCGM-v2.0.pdf.

This is a 200-page document that gives introduction of the Web CGM and the concepts related and some new concepts such as the XML companion file and the DOM Document Object Model, and their relationship with the Web CGM Profile.

Cruikshank, D., *WebCGM Version 2.0*, 2007 [Online]. Available: http://docs.oasis-open.org/webcgm/v2.0/OS/webcgm-v2.0.pdf.

WebCGM is a set of specifications targeted especially at the effective application of the ISO CGM:1999 standard to representation of two-dimensional (2D) graphical content within Web documents.

Danzy, G.B., ProjectWise Collaboration Update.

ProjectWise Web Explorer Lite is a feature of ProjectWise that allows web access to a ProjectWise System.

Dayhuff Group and Ohio Department of Transportation District 2 Office, *PS&E and Pre-Bid Design Specification and Requirements Document*, The Dayhuff Group, Worthington, Ohio, 2001 [Online]. Available: http://www.dot.state.oh.us/dist2/DocImaging/Workflow/dotfs.pdf.

This document is intended to overview the application requirements and provide a framework and roadmap for the final application(s), system, and implementation specifications for Phase I. This is a "living" document and is subject to user and provider review and modification.

Decker, S. and S. Melnik, *The Semantic Web: The Roles of XML and RDF*, 2000 [Online]. Available: http://csdl.computer.org/dl/mags/ic/2000/05/w5063.pdf.

XML and RDF are the current standards for establishing semantic interoperability on the Web, but XML addresses only document structure. RDF better facilitates interoperation because it provides a data model that can be extended to address sophisticated ontology representation techniques.

Decker, S., P. Mitra, and S. Melnik, *Framework for the Semantic Web: An RDF Tutorial*, 2000 [Online]. Available: http://csdl.computer.org/dl/mags/ic/2000/06/w6068.pdf.

RDF tutorial with its built-in notion of resources and relationship between resources, RDF aims to fulfill the promise to populate the Web with machine-processable information. The simplicity of the RDF data model makes representing data straightforward, and more sophisticated representation languages such as the Unified Modeling Language and Description Logics can be defined along with RDF.

DeMartini, T., A. Nadalin, C. Kaler, R. Monzillo, and P. Hallam-Baker, *Web Services Security Rights Expression Language (REL) Token Profile*, 2004 [Online]. Available: http://docs.oasis-open.org/wss/oasis-wss-rel-token-profile-1.0.pdf.

This document describes how to use ISO/IEC 21000-5 Rights Expressions with the Web Services Security: SOAP Message Security [WS-Security] specification.

Diewald, W., "New TRB Special Report: The Workforce Challenge: Recruiting, Training, and Retaining Qualified Workers for Transportation and Transit Agencies," *TR News*, No. 229, 2003, pp. 27–30.

The study did not measure the shortfalls of labor force supply; however, the committee examined strategies and made recommendations for transportation agencies to alter human resources activities—specifically, recruitment, training, retention, and succession management—to meet emerging workforce challenges and to adjust to the labor market. The study also addressed the leadership role of the federal government in this area.

Dingley, A. and P. Shabajee, *Use of RDF for Content Repurposing on the ARKive Project* [Online]. Available: http://csdl.computer.org/dl/proceedings/icalt/2001/1013/00/10130199.pdf.

This paper reports on prototype systems to provide an infrastructure for the dynamic and flexible repurposing of multimedia resources held in a large database. The database, called ARKive, holds film, stills, audio, and text about globally endangered and native U.K. animal and plant species as well as their habitats. It aims to offer a wide range of users customized access to both the core multimedia data and full integration of core data with external educational resources. Aspects covered in the paper include designing for repurposing with respect to specific audiences, storage, and querying using RDF, XSL, SMIL, and related technologies. The advantages of the approaches taken are discussed and key issues are highlighted.

Dubray, J.-J., S. St Amand, and M.J. Martin, *ebXML Business Process Specification Schema Technical Specification*

*Appendices v2.0.4*, 2006 [Online]. Available: docs. oasis-open.org/ebxml-bp/2.0.4/OS/spec/ebxmlbp-v2.0.4-Spec-os-Appendices-en.pdf.

This document has appendices for OASIS Standard and an introduction of the appendices such as business service interface, manual or implicit business transactions, and handling recursive and optional activities.

Dubray, J.-J., S. St Amand, and M.J. Martin, *ebXML Business Process Specification Schema Technical Specification v2.0.4*, 2006 [Online]. Available: docs.oasis-open.org/ebxml-bp/2.0.4/OS/spec/ebxmlbp-v2.0.4-Spec-os-en.pdf.

This document defines a standards-based business process foundation that promotes the 45 automation and predictable exchange of Business Collaboration definitions using XML.

Durusau, P., *Open Document Format for Office Applications*, 2006 [Online]. Available: http://docs.oasis-open.org/office/v1.1/OS/OpenDocument-v1.1.pdf.

This is the specification of the Open Document Format for Office Applications (OpenDocument) format, an open, XML-based file format for office applications, based on OpenOffice.org XML [OOo].

Durusau, P., *Reference Model for Service Oriented Architecture*, 2006 [Online]. Available: http://docs.oasis-open.org/soa-rm/v1.0/soa-rm.pdf.

This *Reference Model for Service Oriented Architecture* (SOA) is an abstract framework for understanding significant entities and relationships between them within a service-oriented environment, and for the development of consistent standards or specifications supporting that environment. It is based on unifying concepts of SOA and may be used by architects developing specific service-oriented architectures or in training and explaining SOA. A reference model is not directly tied to any standards, technologies, or other concrete implementation details. It does seek to provide common semantics that can be used unambiguously across and between different implementations. The relationship between the reference model and particular architectures, technologies, and other aspects of SOA is illustrated in Figure 1. Although service orientation may be a popular concept found in a broad variety of applications, this reference model focuses on the field of software architecture. The concepts and relationships described may apply to other service environments; however, this specification makes no attempt to completely account for use outside of the software domain.

Eisenhart, M. and P. Bercich, *Real-Time Kinematic* (*RTK*) *GPS Specifications*, Department of Transportation State of Wyoming, Cheyenne, 2006.

Eklund, P., *OntoRama: Browsing RDF Ontologies Using a Hyperbolic-Style Browser*, 2002 [Online]. Available: http://csdl.computer.org/dl/proceedings/cw/2002/1862/00/18620405.pdf.

This paper presents a Java-based hyperbolic-style browser designed to render RDF files as structured ontological maps. The program was motivated by the need to browse the content of a web-accessible ontology server: WEBKB-2. The ontology server contains descriptions of more than 74,500 object types derived from the WORDNET 1.7 lexical database and can be accessed using RDF syntax. Such a structure creates complications for hyperbolic-style displays. In WEBKB-2 there are 140 stable ontology link types and a hyperbolic display needs to filter and iconify the view so different link relations can be distinguished in multilink views. The browsing tool, ONTORAMA, is therefore motivated by two possibly interfering aims: (1) to display up to 10 times the number of nodes in a hyperbolic-style view rather than using a conventional graphics display; (2), to render the ontology with multiple links comprehensible in that view.

Enterprise Resource Planning, *Enterprise Resource Planning System* [Online]. Available: http://www.durhamnc.gov/departments/bms/05cip/VI-pro.pdf.

This project includes the acquisition and implementation of an Enterprise Resource Planning (ERP) system that will replace the current financial accounting and reporting, utility billing, and human resources systems. The ERP system will be a fully integrated application that will support a wide range of business functions working from centralized information. It will provide a comprehensive management information solution that will simplify reporting and analysis. The project also includes the automation and standardization of business practices as a primary component of system implementation.

Fallon, K.K. and M.E. Palmer, *Capital Facilities Information Handover Guide*, National Institute of Standards and Technology, Gaithersburg, Md., 2006.

All developed nations invest a substantial portion of their gross domestic product in capital facilities—their planning, design, construction, operation, maintenance, renovation, and decommissioning. There is increasing pressure on the global capital facilities industry to perform more efficiently. Since the late 1990s, a number of studies have addressed this issue and provided analyses and recommendations.

Fallon, K.K. and M.E. Palmer, *Capital Facilities Information Handover Guide, Part 1*, National Institute of Standards and Technology, Gaithersburg, Md., 2006.

This guide is designed to address the first two challenges. It defines a methodology for defining the information requirements for the full facility life cycle and then developing and implementing an information handover plan for a specific capital facility project.

FIATECH, *FIATECH Interoperability Projects Status Roadmap* (*2005–2006*), 2006.

*Fiscal Survey of States: National Governors Association*, National Association of State Budget Officers and National Governors Association, Washington, D.C., 2006.

The *Fiscal Survey of States* is published twice annually by the National Association of State Budget Officers and the National Governors Association. The series was started in 1979. The survey presents aggregate and individual data on the states' general fund receipts, expenditures, and balances.

Fornes, D., *Accelerating Interoperability in Capital Projects*, 2007 [Online]. Available: http://enr.construction.com/people/blogs/fornes/070507.asp.

Accelerated Deployment of ISO 15926 (ADI) is a collaborative effort led by FIATECH to establish a universal platform for improving the interoperability in the life cycle of capital projects and facilities.

Fujiia, S. and T. Gärling, "Application of Attitude Theory for Improved Predictive Accuracy of Stated Preference Methods in Travel Demand Analysis," *Transport Research A: Policy & Practice,* Vol. 37, No. 4, 2003, pp. 382–402.

The objective of this paper is to outline an alternative conceptual framework for travel demand analysis that draws on attitude theory from social psychology. In line with this theory, stated choices are interpreted as behavioral intentions. The theory then explains why behavioral intention sometimes deviates from actual behavior. In an empirical demonstration using panel data obtained from commuters ($n = 903$) before and after the opening of a new subway line in Kyoto, Japan, support is obtained for several predictions about why behavioral intentions are, or are not, implemented.

Gallaher, M.P., A.C. Connor, J.L. Dettbarn, Jr., and L.T. Gilday, *AASHTOWare Standards & Guidelines Notebook*, National Institute of Standards and Technology, Gaithersburg, Md., 2004.

The Special Committee on Joint Development formed the Technical & Application Architecture Task Force to provide standards and technical guidance for the development of AASHTOWare software products. The purpose of these standards and guidelines was and is to maximize the return on investment, improve the quality, and increase the usefulness of the products.

Gallaher, M.P., A.C. O'Connor, J.L. Dettbarn, Jr., and L.T. Gilday, *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry*, National Institute of Standards and Technology, Gaithersburg, Md., 2004.

This study includes design, engineering, facilities management, and business processes software systems and redundant paper records management across all facility life-cycle phases. Based on interviews and survey responses, $15.8 billion in annual interoperability costs were quantified for the capital facilities industry in 2002. Of these costs, two-thirds are borne by owners and operators, which incur most of these costs during ongoing facility operation and maintenance. In addition to the costs quantified, respondents indicated that there were additional significant inefficiency and lost opportunity costs associated with interoperability problems that were beyond the scope of this analysis. Thus, the $15.8 billion cost estimate developed in this study was probably a conservative figure.

Gärling, T., R. Gillholm, and A. Gärling, "Reintroducing Attitude Theory in Travel Behavior Research: The Validity of an Interactive Interview Procedure to Predict Car Use," *Transportation* (the Netherlands), Vol. 25, No. 2, 1998, pp. 129–146.

A methodological challenge is to develop methods that satisfy the need in transport planning of accurately forecasting travel behavior. Drawing on a review of the current state of attitude theory, it is argued that successfully forecasting travel behavior relies on a distinction between planned, habitual, and impulsive travel. Empirical illustrations are provided in the form of stated-response data from two experiments investigating the validity of an interactive interview procedure to predict household car use for different types of trips, either before or after participants were required to reduce use.

Geiger, S., *Unlocking Design Data*, New York State Department of Transportation, Albany, N.Y.

Geyer, C., *OASIS Forms CGM Member Section to Advanced WebCGM Graphics Standard*, 2004 [Online]. Available: http://www.oasisopen.org/news/oasis_news_08_04_04.pdf.

An aggressive agenda built around advanced development and interoperability of the Web CGM Standard. Web CGM is developed to accelerate the adoption, application, and implementation of the Computer Graphics Metaphile for the open interchange of structural graphical objects and their attributes that provides a reliable method of publishing 2D technical graphics on the web.

*Global Collaboration on Construction R&D Strategies,* June 15–16, 2005.

This report provides a record of the summit event that took place in Helsinki in June 2005. The background for the event and the study that preceded it are initially presented and then the content of the summit is briefly described, allowing the reader to refer to the annex for fuller detail of the presentations and group work that took place.

Godik, S. and T. Moses, *eXtensible Access Control Markup Language* (*XACML*) *Errata 001*, 2003 [Online].

Available: http://www.oasis-open.org/committees/xacml/repository/errata-001.pdf.

This document contains a list of errata against XACML OASIS Standard Version 1.0 that 28 have been approved by the XACML Technical Committee.

Godik, S. and T. Moses, *eXtensible Access Control Markup Language* (*XACML*) *Version 1.0*, 2003 [Online]. Available: http://www.oasis-open.org/committees/xacml/repository/cs-xacml-core-01.pdf.

This specification defines an XML schema for an extensible access-control policy language.

Gordon, M., *An Introduction to RDF Technologies: Too Little Too Soon*, 2004 [Online]. Available: http://csdl2.computer.org/comp/mags/ds/2004/08/o8005.pdf.

The Resource Description Framework is to the emerging semantic web what HTML is to the current World Wide Web. The semantic web is not a new web, but an extension of the current one; likewise, the Resource Description Framework is not a new HTML, but a framework for making logical assertions about resources on the web, including existing HTML web pages. The semantics are in the connections between assertions, which form a semantic web.

Graham, S., D. Hull, and B. Murray, *Web Services Base Notification 1.3*, 2006 [Online]. Available: http://docs.oasis-open.org/wsn/wsn-ws_brokered_notification-1.3-spec-os.pdf.

The event-driven, or notification-based, interaction pattern is a commonly used pattern for inter-object communications. Examples exist in many domains; for example, in publish/subscribe systems provided by Message Oriented Middleware vendors, or in system and device management domains. This notification pattern is increasingly being used in a web services context.

Graham, S., A. Karmarkar, J. Mischkinsky, I. Robinson, and I. Sedukhin, *Web Services Resource 1.2*, 2006 [Online]. Available: http://docs.oasis-open.org/wsrf/wsrf-ws_resource-1.2-spec-os.pdf.

This specification defines a web services resource, which describes the relationship between a web service and a resource in the web services resource framework. This document also defines the pattern by which resources are accessed through web services, and the means by which web services resources are referenced.

Graham, S. and J. Treadwell, *Web Services Resource Properties 1.2*, 2006 [Online]. Available: http://docs.oasis-open.org/wsrf/wsrf-ws_resource_properties-1.2-spec-os.pdf.

This specification standardizes the means by which the definition of the properties of a web services resource may be declared as part of the web service interface. The declaration of the web services resource's properties represents a projection of or a view on the resource's state.

Harvey, F., W. Kuhn, H. Pundt, Y. Bishr, and C. Riedemann, "Semantic Interoperability: A Central Issue for Sharing Geographic Information," *The Annals of Regional Science*, Vol. 33, No. 2, 2004.

This paper presents an overview of semantic interoperability and through case studies shows the breadth and depth of issues and approaches in different countries and at different levels of organizations. These cases illustrate the importance of developing flexible approaches to practical data sharing problems that merge semantical with technical considerations. Based on our examinations of semantic issues and approaches in ongoing research projects, we propose cognitive, computer science, and socio-technical frameworks for examining semantic interoperability.

Haydarlou, A.R., *Using Semantic Web Technology for Self-Management of Distributed Object-Oriented Systems*.

Automated support for management of complex distributed object-oriented systems is a challenge: self-management the goal. A self-management system needs to reason about the behavior of the distributed entities in a system and act when necessary. The knowledge needed is multileveled: different levels of concepts and rules need to be represented. This paper explores the requirements that hold for representing this knowledge in self-managed distributed object-oriented systems, and explores the potential of semantic web technology in this context. A model for self-management knowledge and a simplified version of a real-life use case is used to illustrate the potential.

Helsinki Implementation Initiative, *Global Collaboration on Construction R&D Strategies: The Helsinki Implementation Initiative*, Helsinki, 2005.

This report provides a record of the summit event that took place in Helsinki on June 15–16, 2005. The background for the event and the study that preceded it are initially presented and then the content of the summit is briefly described, allowing the reader to refer to the annex for fuller detail of the presentations and group work that took place.

Helsinki Implementation Initiative, *Pre-Summit Study: Global Synthesis Report*, 2005.

This document presents summary data and a synthesis view from a comparison of 16 documents, which to some extent represent the industry-wide expressions of strategic intent from different countries around the world.

Hollmann, J.K., *Total Cost Management Framework*, Morgantown, W. Va., AACE International, 2006.

Horridge, M., H. Knublauch, A. Rector, R. Stevens, and C. Wroe, *A Practical Guide to Building OWL Ontologies Using the Protege-OWL Plugin and CO-ODE Tools*, The University of Manchester, Manchester, U.K., 2004.

This work was supported in part by the CO-ODE project funded by the U.K. Joint Information Services Committee and the HyOntUse Project (GR/S44686) funded by the U.K. Engineering and Physical Science Research Council and by 21XS067A from the National Cancer Institute.

This guide introduces the Protege-OWL plugin for creating OWL ontologies. Chapter 3 gives a brief overview of the OWL ontology language. Chapter 4 focuses on building an OWL-DL ontology and using a Description Logic Reasoner to check the consistency of the ontology and automatically compute the ontology class hierarchy. Chapter 6 describes some OWL constructs such as Value Restrictions and Enumerated Classes, which are not directly used in the main tutorial. Chapter 7 describes namespaces, importing ontologies, and various features and utilities of the Protege-OWL application.

Information Technology Company, *Trns-port Transportation Software Management Solution*, American Association of State Highway and Transportation Officials, Gainesville, Fla., 2004.

The client/server Trns-port modules have a multitiered architecture. Each module uses one or more types of server that can be deployed in many different configurations. There are performance and server availability factors that should be considered when planning an agency's server configuration. It includes a description of the server types, server requirements, and configuration options, and provides example configurations.

Jha, M.K., C. McCall, and P. Schonfeld, *Using GIS, Genetic Algorithms, and Visualization in Highway Development,* 2001 [Online]. Available: http://www.blackwell-synergy.com/doi/abs/10.1111/0885-9507.00242.

A model for highway development is presented, which uses geographic information systems (GIS), genetic algorithms (GA), and computer visualization (CV). GIS serves as a repository of geographic information and enables spatial manipulations and database management. GAs are used to optimize highway alignments in a complex search space. CV is a technique used to convey the characteristics of alternative solutions, which can be the basis of decisions. The proposed model implements GIS and GA to find an optimized alignment based on the minimization of highway costs. CV is implemented to investigate the effects of intangible parameters, such as unusual land and environmental characteristics not considered in optimization. Constrained optimization using GAs may be performed at subsequent stages if necessary using feedback received from CVs. Implementation of the model in a real highway project from Maryland indicates that integration of GIS, GAs, and CV greatly enhances the highway development process.

Johnson, J., B. Nilsson, F. Luise, A. Torne, J.-L. Loeuillet, L. Candy, M. Inderst, and D. Harris, *The Future Systems Engineering Data Exchange Standard STEP AP-233: Sharing the Results of the SEDRES Project.*

Sharing design information during the systems engineering activities on large international projects within virtual enterprises faces many challenges, including working with heterogeneous sets of systems engineering tools. The adoption of neutral data exchange standards is one appropriate approach now well advanced in areas such as structural design (computer-aided design or CAD). ESPRIT project 20496, "SEDRES," has made significant progress in producing a neutral data exchange standard based on STEP (ISO-10303), embracing systems engineering design data. SEDRES stands for Systems Engineering Data Representation and Exchange Standardization. Cofunded by the European Commission and running from 1996–1999, SEDRES was initiated by Aerospatiale, Alenia, British Aerospace, DASA, and Saab.

Kessler, D.S., *TCRP Synthesis 57: Computer-Aided Scheduling and Dispatch in Demand-Responsive Transit Services*, Transportation Research Board, National Research Council, Washington, D.C., 2004, 87 pp.

The scope of this synthesis is to (1) search out useful information on the use of computer-aided scheduling and dispatch (CASD) in demand-responsive transit (DRT) services, (2) develop an amalgamation or compendium of the current knowledge and successful practices used in computerizing the functions necessary to efficiently and effectively operate such DRT services, and (3) report on measures used to resolve specific problems in planning and implementing CASD. The ultimate objective in compiling a considerable storehouse of information is to make this information available to the public transit community. Private and nonprofit organizations that are providing DRT services will similarly benefit from a review of these results.

Klein, M., *Interpreting XML Documents via an RDF Schema Ontology* [Online]. Available: http://csdl.computer.org/dl/mags/ex/2001/02/x2026.pdf.

This document proposes a procedure that transforms ambiguous XML data into useful RDF statements. This procedure depends on an ontology that describes the meaning of the data.

Klein, M., *Tutorial: The Semantic Web*, 2001 [Online]. Available: http://csdl.computer.org/dl/mags/ex/2001/02/x2026.pdf.

XML and RDF are different formalisms with their own purposes, and their roles in the realization of the semantic web vision will be different. XML aims to provide an easy-to-use

syntax for web data. With it you can encode all kinds of data that are exchanged between computers, using XML schemas to prescribe the data structure. This makes XML a fundamental language for the semantic web in the sense that many techniques will probably use XML as their underlying syntax.

Kratt, D., *Design Memorandum No. 18-05*, Department of Highway Design, 2005.

Electronic files submittal with the final contract plans

Kreger, H., *Web Services Distributed Management: Management of Web Services*, 2006 [Online]. Available: http://docs.oasis-open.org/wsdm/wsdm-mows-1.1-spec-os-01.pdf.

The Web Services Distributed Management (WSDM) specifications, as declared in the committee charter, define (1) how management of any resource can be accessed via web services protocols û management using web services, and (2) management of the web services resources via the former û management of web services. This document is the web services distributed management specification defining management of web services.

Kreger, H., *Web Services Distributed Management: Management Using Web Services Part 1*, 2006 [Online]. Available: http://docs.oasis-open.org/wsdm/wsdm-muws1-1.1-spec-os-01.pdf.

Management using web services (MUWS) enables management of distributed information technology (IT) resources using web services. Many distributed IT resources use different management interfaces. By leveraging web service technology, MUWS enables easier and more efficient management of IT resources.

Kreger, H., *Web Services Distributed Management: Management Using Web Services Part 2*, 2006 [Online]. Available: http://docs.oasis-open.org/wsdm/wsdm-muws2-1.1-spec-os-01.pdf.

This document, MUWS Part 2, builds on the foundation provided by MUWS Part 1. All of the normative text presented in MUWS Part 1 is considered normative text for MUWS Part 2. All informational text presented in MUWS Part 1 is relevant informational text for MUWS Part 2. Compliance with MUWS Part 1 is required for every aspect of MUWS Part 2.

Kukawka, A., *IMC Monthly Project Status Report, Department of Transportation*, 2005.

Lange, D.B., *Mobile Objects and Mobile Agents: The Future of Distributed Computing*, Springer, Berlin/Heidelberg, 2006.

This report leads into the world of mobile agents, an emerging technology that makes it very much easier to design, implement, and maintain distributed systems. Mobile agents reduce the network traffic, provide an effective means of overcoming network latency, and perhaps most importantly, through their ability to operate asynchronously and autonomously of the process that created them, helps to construct more robust and fault-tolerant. There is an introduction to software agents—the mobile as well as the stationary ones. All the benefits of mobile agents are explained and their impact on the design of distributed systems is demonstrated. This report concludes with a brief overview of some contemporary mobile agent systems.

Lassila, O., *Generating Rewrite Rules by Browsing RDF Data*, 2006 [Online]. Available: http://csdl.computer.org/dl/proceedings/ruleml/2006/2652/00/26520051.pdf.

The OINK system presented in this paper allows users access to RDF data via browsing and the system as a debugging tool when building semantic web applications. OINK also allows users to interactively build queries in the WILBURQL path query language merely by browsing their data; navigational paths are translated into path queries.

Law, K.H., "Applications of ICT Standards in Engineering," In *Open ICT Ecosystems*, National Institute of Standards and Technology, Gaithersburg, Md., 2006.

The document explains the standards of software interoperability and demonstrates that it is not merely to exchange data, but it has extended application functionalities.

Lawrence, K. and C. Kaler, *WS-SecureConversation 1.3*, 2007 [Online]. Available: http://docs.oasis-open.org/ws-sx/ws-secureconversation/200512/ws-secureconversation-1.3-os.pdf.

This specification defines extensions that build on Web Services Security to provide a framework for requesting and issuing security tokens and to broker trust relationships.

Lee, R.W., Ed., *Preparation and Transfer of Electronic Engineering Data*, New York State Department of Transportation, Albany, N.Y., 2005.

The purpose of this text is to remind all involved in the design and/or delivery of capital projects for letting by the department of the guidance regarding the preparation and transfer of electronic engineering data.

Lim, J., A. Yoon, and C.-H. Sun, *OntoSNP: Ontology Driven Knowledgebase for SNP*, 2006 [Online]. Available: http://csdl.computer.org/dl/proceedings/ichit/2006/2674/02/267420120.pdf.

This document explains OntoSNP, the information system model based on ontology and reasoning for the purpose of biomedical research. Its main functionality is to query about the mitochondrial SNP, gene, and disease information related to one another.

Liu, L. and S. Meder, *Web Services Base Faults 1.2,* 2006 [Online]. Available: http://docs.oasis-open.org/wsrf/wsrf-ws_ base_faults-1.2-spec-os.pdf [accessed Mar. 31, 2007].

Problem determination in a web services setting is simplified by standardizing a base set of information that may appear in fault messages. Web Services-BaseFaults defines an XML schema type for base faults, along with rules for how this base fault type is used and extended by web services.

Liu, S. and J. Zhang, *Retrieving and Matching RDF Graphs by Solving the Satisfiability Problem*. [Online]. Available: http://csdl.computer.org/dl/proceedings/wi/2006/2747/00/274700510.pdf.

The Resource Description Framework (RDF) has been accepted as a standard for semantic representation of resources. Efficient methods and tools are needed to solve problems emerging from RDF-based systems; for example, checking equality of two RDF graphs and retrieving subgraphs from another RDF graph. This paper proposes a method that encodes these problems into satisfiability (SAT) instances and solves them by employing efficient SAT solvers. A prototype tool is implemented and preliminary experimental results are given.

Liu, S. and J. Zhang, *Exploring Large Document Repositories with RDF Technology: The DOPE Project Retrieving and Matching RDF Graphs by Solving the Satisfiability Problem*, 2004 [Online]. Available: http://www.cs.vu.nl/~frankh/postscript/IEEE-IS04.pdf.

This thesaurus-based search system uses automatic indexing, RDF-based querying, and concept-based visualization of results to support exploration of large online document repositories. The DOPE project (Drug Ontology Project for Elsevier) explores ways to provide access to multiple life science information sources through a single interface.

Maguire, T., D. Snelling, and T. Banks, *Web Services ServiceGroup 1.2*, 2006 [Online]. Available: http://docs.oasis-open.org/wsrf/wsrf-ws_service_group-1.2-spec-os.pdf.

A ServiceGroup is a heterogeneous by-reference collection of web services. ServiceGroups can be used to form a wide variety of collections of services or WS16 Resources [web services (WS)-Resources], including registries of services and associated WS-Resources. Members of a ServiceGroup are represented using components called entries. A ServiceGroup entry is a WS-Resource. The web service associated with a ServiceGroup entry can be composed from a variety of web services standards including WS20 Resource Lifetime, which defines standard patterns by which resources can be destroyed, WS-BaseNotification, which defines how third parties may subscribe to be informed of changes to the ServiceGroup, and WS23 ResourceProperties, which defines how the properties of a ServiceGroup and its entries are made accessible through a web service interface.

Mason, J. and E. Deakin, *Information Technology—Implications for Transportation*, University of California Transportation Center, Berkeley, Calif., 2001.

This paper discusses the increased demand for travel and the telecommunication transportation relationship, the difficulty of getting large-scale infrastructure built and the possibility of using information technology as an alternative, and lessons for successful implementation.

MAXIMUS, *Best Practices and Lessons Learned: The Office of the Comptroller of the State of New York*, Reston, Va., 2002.

This document details the results of the best practice analysis performed by MAXIMUS and documents the resultant findings. As OSC moves forward with a solution for CAS, it is critical to understand the best practices and lessons learned from other comparable state and/or large city initiatives.

McLawhorn, N., *Process Mapping for DOT Business Functions,* 2005.

Transportation Synthesis Reports are brief summaries of currently available information on topics of interest to Wisconsin DOT staff. Online and print sources include NCHRP and other TRB programs, AASHTO, the research and practices of other state DOTs, and related research and news.

Melas, P., *AASHTO Technology Implementation Group Nomination of Technology Ready for Implementation*, New York State Department of Transportation, Albany, N.Y., 2005.

Field Automated Communication System (FACS) incorporates existing DOT programs and e-mail access to interface with the tablets, thereby allowing coordination with staff for progress of work and changed work that allows for efficient accounting. Additionally, the FACS ability for real-time input shall provide timely evaluation of any potential impacts or delays to the overall project schedule.

Melas, P., *Technology Implementation*, 2005.

The topics covered are: Bentley Inspector and Stakeout, machine navigation/control, stake-less construction, field information management system, Trns-port SiteManager, and Internet bidding.

Missouri Department of Transportation, *Specifications of Computer Deliverable Contract Plans*, 2000.

The Missouri DOT uses MicroStation for highway and bridge design and drafting. Highway design surveys and road design computation are achieved by using the GEOPAK software.

Mitretek Systems, *E-Transit: Electronic Business Strategies for Public Transportation*, *Volume 2*, Transportation Research Board, National Research Council, Washington, D.C., 2002.

The characteristics and market position of application service providers were investigated, and the strengths and weaknesses of this computing service model were identified. A similar investigation of thin client computing was conducted and reported in this volume.

Mitretek Systems and TransTech Management Inc., *e-Transit: Electronic Business Strategies for Public Transportation, Volume 1*, Transportation Research Board, National Research Council, Washington, D.C., 2002.

This report includes a clarification of supply-chain terms, discussion of the impact of asset management decisions on parts and inventory management needs, and strategies for streamlining the supply chain.

Moses, J., *eXtensible Access Control Markup Language*, 2005 [Online]. Available: http://docs.oasis-open.org/xacml/2.0/access_control-xacml-2.0-core-spec-os.pdf.

This 141-page document is about the 2.0 version of the XACML. It discusses the model, gives some examples, and also explains the syntax and the context of XACML.

Mueser, B. and Bentley Civil, "19th Annual AGC/NYS DOT Technical Conference," In Bentley Inspect/Stakeout, Saratoga Springs, N.Y., Dec. 6–8, 2005.

The topics covered are Bentley Inspect/Stakeout—interoperability: sharing electronic data, electronic deliverables, and DOT pilot projects, machine control/navigation, CORS/VRS, and GPS.

Nadalin, A., M. Goodner, M. Gudgin, A. Barbir, and H. Granqvist, *WS-Trust 1.3*, 2007 [Online]. Available: http://docs.oasis-open.org/ws-sx/ws-trust/200512/ws-trust-1.3-os.pdf.

This specification defines extensions that build on Web Services Security to provide a framework for requesting and issuing security tokens, and to broker trust relationships.

Nejako, H. and K. Shadan, *Demistifying Interoperability—A Basic Tutorial Construction Project Management Handbook*, 2005 [Online]. Available: http://www.fta.dot.gov/documents/Construct_Proj_Mangmnt_CD.pdf.

This handbook provides guidelines to public transit agencies undertaking substantial construction projects either for the first time or with little experience in construction management.

Nelson, D., *New York State Department of Transportation's* (*NYSDOT's*) *Environmental Initiative*, AASHTO Center for Environmental Excellence, Washington, D.C., 2003.

New York State DOT has fostered this environmental ethic agency-wide to empower staff to make decisions that have a positive effect on the environment and urge every New York State DOT employee to look for opportunities to enhance the department's environmental performance.

Njord, J.R., *Glossary of Highway Quality Assurance Terms*, 2005 [Online]. Available: http://onlinepubs.trb.org/onlinepubs/circulars/ec074.pdf.

The purpose of this publication is to provide a reference document containing common usage of highway quality assurance terminology.

North Carolina Department of Transportation, Chapter 5, Section 3—*Cost Allocation*, 2006.

North Carolina DOT has a cost allocation plan to distribute cost to major operating programs such as transportation improvement plan construction, highway maintenance, other programs, and other construction. FHWA requires all states to formulate a plan to distribute overhead cost in compliance with Circular A-87. Certain costs is considered indirect costs because the units benefit from their existence. By charging this cost uniformly across the various areas, FHWA will reimburse DOTs a pro rata share of the cost.

OASIS, *PKI Action Plan*, 2004 [Online]. Available: http://www.oasis-open.org/committees/pki/pkiactionplan.pdf.

Public key infrastructure (PKI) was invented more than 20 years ago. Today, it is used in many important standards and protocols (such as SSL/TLS, IPSEC, etc.). Millions of times each day, someone visits a secure website for shopping or banking and PKI is used to secure the connection.

Orchard, D. and H. Lockhart, *SAML Domain Model*, 2001 [Online]. Available: http://www.oasis-open.org/committees/security/docs/draft-sstc-use-domain-05.pdf.

This domain model provides a description and categorization of the domain in which SAML solves problems. 7 People, software, data, interactions, and behavior are described in the abstract, without binding the specification 8 to a particular implementation.

Osif, B., *Fastlanes on the Transportation Information Highway*, 2006 [Online]. Available: http://onlinepubs.trb.org/onlinepubs/trnews/trnews243infohighway.pdf.

From this small, exclusive network based on technically dense programming, the protocols and interfaces evolved that now are activated at the click of a mouse.

Pedersen, M.B., *Optimization Models and Solution Methods for Intermodal Transportation*, Denmark: Centre for Traffic and Transport, Lyngby, 2005.

This thesis is composed of three papers, each dealing with different aspects in optimization of intermodal transportation and a summary introducing the perceived issues within intermodal transportation and placing the three papers into context. The summary describes the congestion and environmental problems seen in transportation in Europe and discusses why the European Union sees the reestablishment of the rail sector in an intermodal setting as the solution to the problems. The summary illustrates some of the measures and initiatives taken to improve intermodal transportation. The summary presents the concepts behind developing a freight route planner similar to route planners seen in public transit and discusses how that could be beneficial to the transportation sector as a whole while presenting some of the barriers that may be expected in case of implementation.

Phillip, J.T. and K.R. Marshall, *Ohio Department of Transportation District 2 Office PS&E and Pre-Bid Design Functional Specification and Requirements Document*, The Dayhuff Group and National Cooperative Highway Research Program, Baltimore, Md., 2001.

This document describes a high level design for the new document management and workflow process for the office of Ohio DOT District 2.

Powell, R., D. McCoy, T. Wright, and G. Bakolia, *Business Systems Infrastructure Project*, Office of the State Controller, Raleigh, N.C., 2003.

North Carolina state government is a large, multifaceted organization with broad and diverse responsibilities. It must provide a variety of services to its citizens and be accountable for multiple and complex programs. The state is experiencing continuing challenges from budgetary constraints, public desires for expanded services, and taxpayer demands for more effective and efficient operations.

*Pre-Summit Study: Global Synthesis Report,* Helsinki, Finland, 2005.

This document presents summary data and a synthesis view from a comparison of 16 documents, which to some extent represent the industry-wide expressions of strategic intent from different countries around the world.

Priestley, M. and J. Hackos, *OASIS Darwin Information Typing Architecture (DITA) Language Specification v1.0,* 2005 [Online]. Available: http://docs.oasis-open.org/dita/v1.0/dita-v1.0-spec-os-LanguageSpecification.pdf.

This document is part of the technical specification for the DITA architecture. It has 18 chapters, each explaining different types of elements; for example, the task elements, body elements, software elements, programming elements, etc.

Priestley, M. and J. Hackos, *OASIS DITA Information, Markup, and Specialization*, 2005 [Online]. Available: http://docs.oasis-open.org/dita/v1.0/dita-v1.0-spec-os-Architectural Specification.pdf.

DITA is an architecture for creating topic-oriented, information-typed content that can be reused and single-sourced in a variety of ways. It is also an architecture for creating new topic types and describing new information domains based on existing types and domains.

*Project Development Documentation Procedure,* New York State Department of Transportation, Albany, N.Y., 2002

Raab, R., "Workshop on Interim Human Factors Guidelines for Road Systems," 86th Annual Meeting of Transportation Research Board, Washington, D.C., Jan. 21–25, 2007.

Raymond, M., S. Webb, and P.I. Aymond, *Emergency Data Exchange Language (EDXL) Distribution Element, v. 1.0* [Online]. Available: http://docs.oasis-open.org/emergency/EDXL-DE/V1.0.

This specification is related to the Common Alerting Protocol (CAP), which provides an open, non-proprietary digital message format for all types of alerts and notifications. CAP messages are recommended as one of the standardized forms for XML-based message content, to be distributed by this Distribution Element.

Rebolj, D. and K. Menzel, *Semantic Web-Based Resources for Intelligent Mobile Construction Collaboration*, 2004 [Online]. Available: http://www.itcon.org/data/works/att/2004_26.content.00370.pdf.

This paper focuses on the synergy between the semantic web, web services, and agent technologies in the provision of such mobile collaboration support infrastructure. A multitier architecture is presented, which brings together the necessary technology threads, including the semantic web (to provide a framework for shared definitions of terms, resources, and relationships), web services (to provide dynamic discovery and integration), and multi-agent technologies (to help mobile workers accomplish a particular task) to support intelligent mobile collaboration. Future deployment scenarios are presented to illustrate the potential benefits for the construction industry.

Robinson, R.J., *New York State Department of Transportation HEEP Report*, Highway Engineering Exchange Program, 2006 [Online]. Available: http://www.heepweb.org/ProgramsReports/Reports/HEEPAgencyReports/tabid/96/EntryID/7/Default.aspx [accessed June 21, 2007].

New York State DOT is in the process of developing an IT governance framework to ensure that the correct mix of strategic growth, operational support, and required maintenance IT initiatives is pursued. Perceived benefits will include: a closer alignment between IT strategies and department business strategies, accountability in decisions that impact IT, consistency between IT strategy and policy, and maximum return on IT investment.

Schinas, O., D.V. Lyridis, and H.N. Psaraftis, *Introducing E-brokerage in European Transport Services; The Case of the PROSIT Project*, National Technical University of Athens, Athens, Greece.

The use of advanced telematic solutions in the transport sector is already a market trend as well as a policy choice of the European Commission (EC) aiming to improve the overall efficiency of waterborne transport. The research and development project PROSIT, co-funded by the EC, is an effort to introduce telematic technologies in the traditional field of the shipbroker. As middlemen tend to be excluded in an era of "new economy," PROSIT aims to explore the substitution of an actual commercial procedure with web-based tools. PROSIT has been developed through four major case studies (scenarios) involving different states of technology, market needs, and organizational structures. In this paper all scenarios are described, discussed, and evaluated. Given the results of PROSIT, some qualitative issues of e-brokerage and the future of such services are discussed in view of the modular structure of modern enterprises.

Schulze, T., S. Strassburger, and U. Klein, *Migration of HLA into Civil Domains: Solutions and Prototypes for Transportation Applications*, 1999.

The U.S. Department of Defense's High Level Architecture (HLA) for Modeling and Simulation is a mandatory standard for military simulations. The situation in the civil simulation community is different: simulator interoperability is desirable and even required, but there is no driving force to mandate the use of a certain standard. This article addresses the problems that a simulator interoperability standard in the civil world faces and discusses how HLA can possibly become the standard that is needed. Several solutions for connecting civil simulation tools using HLA are introduced and some prototypical applications focusing on the area of transportation are demonstrated.

Science Applications International Corporation, *Outsourcing of State DOT Capital Program Delivery Functions*, Transportation Policy and Analysis Center, Vienna, Va., 2003.

This document was prepared as part of the 20-24 Series of NCHRP projects on the administration of highway and transportation agencies. The report is designed to assist state DOTs in assessing the outsourcing of their capital delivery functions.

Sedukhin, I., *Management of Web Services: Web Services Distributed Management*, 2005 [Online]. Available: http://docs.oasis-open.org/wsdm/2004/12/wsdm-mows-1.0.pdf.

The document explains the formal expression of the management of web services architecture concepts and application to resources exposed as web services. The management of web service concepts and the web architecture is discussed.

SITA, *Can Information Technology Remove Complexity and Enable Change for Travel and Transportation Industry?* 2005 [Online]. Available: http://www.sita.aero/News_Centre/Press_releases/Press_releases_2005/Can_IT_remove_complexity_and_enable_change_for_travel_and_transportation_industry.htm [accessed Feb. 27, 2007].

SITA 2005 Insight Conference gathered industry influencers to discuss convergence, security, and information technology. In an industry with severe challenges, there are no simple solutions. IT is however the enabler for change, to remove complexity, and to deliver pragmatic solutions. SITA, the world's leading provider of network and communications solutions to the Travel and Transportation Industry (TTI), announced its speakers and focus for the 2005 Insight Conference, September 13 to 15 at Doral Tesoro Hotel & Golf Club in Fort Worth, Texas. The conference, in its fifth year, focused on effective ways to use technology solutions to cut airline and airport costs, enhance business process efficiencies, and simplify the travel and transportation industry.

Smith, H., *Building a Quality DTM for New York State Department of Transportation.*

The topics covered are: DTM—digital terrain model, DGN—graphics, ALG—coordinate geometry, SDB—storm and sanitary database, and MDB—quantity manager database.

Solutions, S2, *NavisWorks 3D Design File Formats*, 2006 [Online]. Available: http://www.s2solutions.biz/formats.htm [accessed Sep. 29, 2006].

This table provides an extensive list of the CAD applications currently supported by NavisWorks[3], along with any additional information that may be necessary to review files in NavisWorks.

Special Committee on Joint Development Force, Technical & Application Architecture Task Force, *AASHTOWare Standards and Guidelines*, American Association of State Highway and Transportation Officials, Washington, D.C., 1996.

The Special Committee on Joint Development formed the Technical & Application Architecture Task Force to provide standards and technical guidance for the development of AASHTOWare software products. The purpose of these standards and guidelines was and is to maximize the return on investment, improve the quality, and increase the usefulness of the products.

Srinivasan, L. and T. Banks, *Web Services Resource Lifetime 1.2,* 2006 [Online]. Available: http://docs.oasis-open.org/wsrf/wsrf-ws_resource_lifetime-1.2-spec-os.pdf.

The relationship between web services and stateful resources is defined in WS-Resource. This specification defines message exchanges to standardize the means by which a WS-Resource may be destroyed, and resource properties (WS-ResourceProperties) that may be used to inspect and monitor the lifetime of a WS-Resource. This specification defines two means of destroying a WS-Resource: immediate destruction and time-based, scheduled destruction.

Streett, D., "Emerging Technologies for Highway Construction," In *The Value of Embracing New Technologies*, A. D. T. Conference, 2005.

The topics covered include good data being essential to exploiting technology; increasing confidence in engineering data; 3D modeling of proposed project design; multiple uses of shared electronic data; technology implementations (pilots); machine guidance, control, and navigation; technology uses for inspection and stakeout; and the realities of emerging technologies.

Streett, D., *Survey Technology & Policies*, 2005.

The topics covered include new CORS network and policy changes.

Sutton, J.C., *TCRP Synthesis 55*: *Geographic Information Systems Application in Transit*, Transportation Research Board, Washington, D.C., 2004, 70 pp.

This synthesis will be of interest to transit practitioners and researchers, including technical staff and transit managers, as well as to vendors of Geographic Information System (GIS) solutions. This report illustrates the value of GIS to transit agencies in service provision and in potential cost savings. The report covers the full range of transit services including planning, operations, management, information technology, and customer service. Included are case studies from five large transit operators that demonstrate a number of innovative uses of GIS, as well as illustrate how GIS is becoming a part of mainstream information technology and a core technology in transit information services.

Tarnoff, P.J. and K.R. Marshall, *Considerations for a Guide to Contracting ITS Projects*, NCHRP Web Document No. 85, Transportation Research Board, National Research Council, Washington, D.C., 2005, 249 pp.

The products of this research effort provide transportation professionals with tools to aid in the identification of appropriate innovative procurement strategies for a specific intelligent transportation system (ITS) project. To further advance the use of innovative procurement strategies to procure ITS, an aggressive outreach campaign is suggested.

Tavasszy, L., W. Jonkhoff, A. Burgess, M. Rustenburg, and A. Hunt, *Developing Harmonized European Approaches for Transport Costing and Project Assessment,* 2005.

This report presents the first results of WP2 of the harmonized European approaches for transport costing (HEATCO) project. It presents state-of-the-art insights into transport project appraisal. It accomplishes this by first trying to indicate existing evaluation frameworks in countries. Based on the research carried out in the HEATCO project so far, the advantages and drawbacks of main elements of evaluation harmonization are discussed. Furthermore, it deals with those methodological questions that demand that a choice be made in the harmonization framework. Bearing this in mind, this is an issue paper to guide further research in the HEATCO project. It is meant to identify the relevant issues for further research and to indicate the questions that need to be answered.

Teague, T., "FIATECH Interoperability Projects Status Roadmap (2005–2006)," In *Interoperability Needs & Data Standards*, 2006.

This project combines two existing FIATECH projects [DSC and IRR (Interoperability Requirements for the Roadmap)]. The focus of this project is the first step in the FIATECH Interoperability Work Process to identify high business value usage scenarios and project opportunities. While this project has a long-term goal to identify all high-value opportunities across the facility's life cycle, it uses an incremental approach so high business value projects can be started at any time.

Teague, T., *Interoperability Needs & Data Standards,* FIATECH, 2006 [Online] available: http://www.fiatech.org/projects/idim/inds.htm [accessed Sep. 5, 2006].

This project combines two existing FIATECH projects [Data Standards Clearinghouse (DSC) and Interoperability Requirements for the Roadmap (IRR)]. The focus of this project is the first step in the FIATECH Interoperability Work Process to identify high business value usage scenarios and project opportunities. While this project has a long-term goal to identify all high-value opportunities across the facility's life cycle, it uses an incremental approach so high business value projects can be started at any time.

Teague, T.L., *Capital Facilities Industry Interoperability Technical Framework Definition*, 2005.

This is intended to be a discussion draft, incorporating the ideas of the initial draft of the FIATECH *Capital Projects*

*Technology Roadmap Element 9—Lifecycle Data Management and Information Integration Technical Framework*, published in October 2004, and incorporating initial results from the *Interoperability Requirements for the Roadmap* (*IRR*) *Project*.

Tiede, R., *Sanitary Sewer*, Larsen Engineers, Rochester, N.Y.

An illustration of a sanitary sewer main design completed for a local town. It will be incorporated in a New York State DOT design for construction during other highway construction that is designed by that agency.

Trans-port, *Trans-port Platform Component Status by Year*, 2007.

FieldNet and Trns-port Intranet are supported on Oracle databases.

Transportation Research Board, *NCHRP Report 371*: *State Departments of Transportation: Strategies for Change*, Transportation Research Board, National Research Council, Washington, D.C., 1995, 139 pp.

This report documents and summarizes the results of a two-phase project involving: (1) field research and analysis of factors driving change in transportation and state DOTs and the impacts on state DOTs; and (2) the most effective strategies for DOTs to respond effectively.

Travis, J., CEC/NCDOT Joint Subcommittee on CEI, *Meeting Minutes*, Charlotte, N.C., July 11, 2001.

Travis, J., CEC/NCDOT Joint Subcommittee on CEI, *Meeting Minutes*, Raleigh, N.C., June 7, 2001.

The first CEC/NCDOT Joint Subcommittee on CEI, June 7, 2001, at the North Carolina DOT Highway Design Conference Room located at the Century Center Complex, Raleigh, North Carolina

Tuchman, J.L., *Owners Tackle Work Force and Process Transformation*, 2006 [Online]. Available: http://enr.ecnext.com/comsite5/bin/enr_description_docview_save.pl?p.

CURT leaders envision solutions coming from "process transformation" in the industry. Its strategy group called 3xPT, a collaboration with the American Institute of Architects and the Associated General Contractors (ACG) of America, reported that it will involve every sector from engineers and subcontractors to suppliers and attorneys in the drive toward collaboration. AGC's John Tocci called on owners to share the cost of adoption of new technology tools that will reduce the cost of design and construction and create a "litigation-free zone" around building information modeling.

Tuchman, J.L., "Owners Tackle Work Force and Process Transformation," *Engineering News-Record*, Nov. 27, 2006.

Bold cooperative action to alleviate the industry's shortfall in craft workers "must begin today because tomorrow will be too late," said veteran labor relations analyst Peter A. Cockshaw in a fire and brimstone message to owners at the Construction Users Roundtable national conference in Tucson, Arizona, Nov. 13–15, 2006.

Vambenepe, W., *Web Service Distributed Management*, 2005 [Online]. Available: http://docs.oasis-open.org/wsdm/2004/12/wsdm-muws-part1-1.0.pdf.

This document describes how web service technology can be used to connect information technology to remote locations for manageability interface. Management using web services (MUSW) are used for monitoring the quality of a service, for controlling a task, managing a resource life cycle, and enforcing a service-level agreement.

Vambenepe, W., S. Graham, and P. Niblett, *Web Services Topics 1.3*, 2006 [Online]. Available: http://docs.oasis-open.org/wsn/wsn-ws_topics-1.3-spec-os.pdf.

The event-driven, or notification-based, interaction pattern is a commonly used pattern for inter-object communications. Examples exist in many domains; for example, in publish/subscribe systems provided by Message Oriented Middleware vendors, or in system and device management domains. This notification pattern is increasingly being used in a web services context.

Von Riegen, L., *UDDI Version 2.03 Data Structure Reference*, 2002 [Online]. Available: http://uddi.org/pubs/DataStructure-V2.03-Published-20020719.htm.

The UDDI Version 2.0 API specification defines approximately 40 SOAP messages that are used to perform inquiry and publishing functions against any UDDI compliant service registry. This document outlines the details of each of the XML structures associated with these messages.

Wachs, M., *Improving Efficiency and Equity in Transportation Finance*, The Brookings Institution Series on Transportation Reform, Washington, D.C., 2003.

A complex partnership between many governmental bodies, continually influenced by numerous private, corporate, and civic interests, finances our nation's transportation system. But the nature of the partnership is changing. Originally offset by a variety of user fees, such as tolls and fuel taxes, the burden of financing transportation programs is gradually being shifted to local governments and voter-approved initiatives. This shift to local transportation taxes raises interesting issues for public policy. This brief dissects the arcane and complicated system of transportation funding by describing the relationships that define the federal, state, and local roles. It summarizes the most pressing problems facing the transportation network, and argues that expanded reliance on user fees remains the most promising way to promote equity and efficiency in transportation finance.

Warne, T.R., *State DOT Outsourcing and Private-Sector Utilization*, American Association of State Highway and Transportation Officials, Washington, D.C., 2003.

The topic of outsourcing services by state DOTs is one of much interest and consideration. Capital programs in the states continue to grow at record levels thanks to the Transportation Equity Act for the 21st Century and various state initiatives. Demands on state work forces have never been greater. Consequently, state DOTs are looking for ways to leverage their work forces by outsourcing key activities to deliver products and services to their customers. With limited resources and ever-increasing demands for services, the DOTs are endeavoring to optimize their outsourcing activities. In 1997, *NCHRP Synthesis Report 246*: *Outsourcing of State Highway Facilities and Services* was prepared to capture the nature of outsourcing at that time. This report is an update of that effort and represents the most current knowledge on the subject.

# APPENDIX A
# Survey Questionnaire

**NCHRP SYNTHESIS 38-02**
**INFORMATION TECHNOLOGY for PROJECT DESIGN and CONSTRUCTION**

**INTRODUCTION/BACKGROUND:**

The National Cooperative Highway Research Program (NCHRP) is conducting a synthesis study (existing state-of-the-art information report) of successful transportation agency transfer of information technology (data) and interoperability across agency business functions and to contractors. The resulting report should provide the nation's transportation agencies a detailed roadmap for emulation of agencies that are most successful in this endeavor.

Our initial brief survey attempts to identify agencies that are successfully avoiding redundant information creation, handling, and storage, as well as those that efficiently share data with all project stakeholders.
This brief initial survey should be completed by persons knowledgeable of data transfer practices specific to your various functional areas: planning, design, procurement, construction, operations, and maintenance. Therefore, we ask that you direct each of those survey portions to the appropriate personnel.

The entire scope of the study can be found on the Transportation Research Board's website at http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=107.

The questionnaire is structured into the following five parts:

Part 1—**IT for Planning**: Functional Area commissioned to project planning: i.e., site acquisition, surveying, environmental, traffic flow, and other pre-design requirements.
Part 2—**IT for Design**: Functional Area commissioned to prepare project documents, drawings, and specifications.
Part 3—**IT for Procurement**: Functional Area commissioned to project bidding and contract documents.
Part 4—**IT for Construction**: Functional Area commissioned to project construction management, inspection, and delivery.
Part 5—**IT for Operations and Maintenance**: Functional Area commissioned to ensure safe traffic flow in current transportation infrastructure (surface roads).

**The survey takes approximately 5 minutes to complete for each functional area.**

Multiple respondents from your organization may complete different parts of the questionnaire before all survey sections are aggregated. THE SURVEY IS DESIGNED FOR THE ABILITY TO ACCUMULATE RESPONSES FROM MULTIPLE RESPONDERS. Portions can be completed by persons in multiple locations; simply e-mail this pdf file to the appropriate person(s) in your agency. When all of the sections are completed, the results can be sent to us via e-mail by simply clicking any of the 'Submit by E-mail' buttons on the form (upper corner). PLEASE RENAME THE FILE SENT TO US WITH YOUR DOT DESIGNATION. Alternatively, you may wish to print the survey form to complete on paper and fax to us at 601-266-5717, Attn: John Hannon.

**Please have all portions of the questionnaire completed on or before May 18, 2007.**

Thank you for your assistance with this NCHRP improvement effort. If you have any questions, please contact John Hannon or TJ Lewis (graduate assistant) of The University of Southern Mississippi at 601-266-5550 or via e-mail at john.hannon@usm.edu or tarlei_lewis@yahoo.com.

**NCHRP SYNTHESIS 38-02**
**INFORMATION TECHNOLOGY for PROJECT DESIGN and CONSTRUCTION**

## SECTION 1: IT for PLANNING FUNCTION

What U.S. State Is Your DOT? ☐ Official Functional Unit Name: ☐

Name of Survey Respondent: ☐ Respondent's Job Title: ☐

Respondent's E-mail Address: ☐ Respondent's Phone Number: ☐

IN WHICH FORMAT ARE DATA **PRIMARILY RECEIVED** FROM OTHER UNITS?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

IN WHICH FORMAT ARE DATA **PRIMARILY PROCESSED/GENERATED** INTERNALLY?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

IN WHICH FORMAT ARE DATA **PRIMARILY SENT** TO OTHER UNITS?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

CHECK ALL TYPES OF DATA WHICH YOUR UNIT RECEIVES, PROCESSES/GENERATES, AND/OR SENDS **ELECTRONICALLY**: (Please mark all that apply) and write in data below not listed on right.

**Project Location Data**

Received☐ Processed/Generated☐ Sent☐

**Project Traffic Data**

Received☐ Processed/Generated☐ Sent☐

**Project Environmental Data**

Received☐ Processed/Generated☐ Sent☐

**Project Survey Data**

Received☐ Processed/Generated☐ Sent☐

**Other Data-1** ☐

Received☐ Processed/Generated ☐ Sent☐

**Other Data-2** ☐

Received☐ Processed/Generated☐ Sent☐

**Other Data-3** ☐

Received☐ Processed/Generated☐ Sent☐

**Other Data-4** ☐

Received☐ Processed/Generated☐ Sent☐

**Other Data-5** ☐

Received☐ Processed/Generated☐ Sent☐

**Other Data-6** ☐

Received☐ Processed/Generated☐ Sent☐

May we follow up with you at a later time for more detailed information? ○YES ○NO

**NCHRP SYNTHESIS 38-02**
**INFORMATION TECHNOLOGY for PROJECT DESIGN and CONSTRUCTION**

**SECTION 2: IT for DESIGN FUNCTION**

What U.S. State Is Your DOT? [ ] Official Functional Unit Name: [ ]

Name of Survey Respondent: [ ] Respondent's Job Title: [ ]

Respondent's E-mail Address: [ ] Respondent's Phone Number: [ ]

IN WHICH FORMAT ARE DATA **PRIMARILY RECEIVED** FROM OTHER UNITS?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

IN WHICH FORMAT ARE DATA **PRIMARILY PROCESSED/GENERATED** INTERNALLY?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

IN WHICH FORMAT ARE DATA **PRIMARILY SENT** TO OTHER UNITS?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

CHECK ALL TYPES OF DATA WHICH YOUR UNIT RECEIVES, PROCESSES/GENERATES, AND/OR SENDS **ELECTRONICALLY**: (Please mark all that apply) and write in data below not listed on right.

**Project Boundary Survey Data**
Received☐ Processed/Generated☐ Sent☐

**Project Elevation Survey Data**
Received☐ Processed/Generated☐ Sent☐

**Project Drawings**
Received☐ Processed/Generated☐ Sent☐

**Project Supplemental Specifications**
Received☐ Processed/Generated☐ Sent☐

**Project Pay Items/Quantities**
Received☐ Processed/Generated☐ Sent☐

**Other Data-1** [ ]
Received☐ Processed/Generated☐ Sent☐

**Other Data-2** [ ]
Received☐ Processed/Generated☐ Sent☐

**Other Data-3** [ ]
Received☐ Processed/Generated☐ Sent☐

**Other Data-4** [ ]
Received☐ Processed/Generated☐ Sent☐

**Other Data-5** [ ]
Received☐ Processed/Generated☐ Sent☐

**Other Data-6** [ ]
Received☐ Processed/Generated☐ Sent☐

May we follow up with you at a later time for more detailed information? ○YES ○NO

**NCHRP SYNTHESIS 38-02**
**INFORMATION TECHNOLOGY for PROJECT DESIGN and CONSTRUCTION**

**SECTION 3: IT for PROCUREMENT FUNCTION**

What U.S. State Is Your DOT? ☐ Official Functional Unit Name: ☐

Name of Survey Respondent: ☐ Respondent's Job Title: ☐

Respondent's E-mail Address: ☐ Respondent's Phone Number: ☐

IN WHICH FORMAT ARE DATA **PRIMARILY RECEIVED** FROM OTHER UNITS?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

IN WHICH FORMAT ARE DATA **PRIMARILY PROCESSED/GENERATED** INTERNALLY?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

IN WHICH FORMAT ARE DATA **PRIMARILY SENT** TO OTHER UNITS?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

CHECK ALL TYPES OF DATA WHICH YOUR UNIT RECEIVES, PROCESSES/GENERATES, AND/OR SENDS **ELECTRONICALLY**: Please mark all that apply) and write in data below not listed on right.

**Bidding Documents**
Received☐ Processed/Generated☐ Sent☐

**Project Survey Data**
Received☐ Processed/Generated☐ Sent☐

**Project Drawings**
Received☐ Processed/Generated☐ Sent☐

**Project Supplemental Specifications**
Received☐ Processed/Generated☐ Sent☐

**Project Pay Items/Quantities**
Received☐ Processed/Generated☐ Sent☐

**Bid Results/Bid Tabulations**
Received☐ Processed/Generated☐ Sent☐

**Other Data-1** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-2** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-3** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-4** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-5** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-6** ☐
Received☐ Processed/Generated☐ Sent☐

May we follow up with you at a later time for more detailed information? ○YES ○NO

**NCHRP SYNTHESIS 38-02**
**INFORMATION TECHNOLOGY for PROJECT DESIGN and CONSTRUCTION**

## SECTION 4: IT for CONSTRUCTION FUNCTION

What U.S. State Is Your DOT? ☐ Official Functional Unit Name: ☐

Name of Survey Respondent: ☐ Respondent's Job Title: ☐

Respondent's E-mail Address: ☐ Respondent's Phone Number: ☐

IN WHICH FORMAT ARE DATA **PRIMARILY RECEIVED** FROM OTHER UNITS?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

IN WHICH FORMAT ARE DATA **PRIMARILY PROCESSED/GENERATED** INTERNALLY?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

IN WHICH FORMAT ARE DATA **PRIMARILY SENT** TO OTHER UNITS?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

CHECK ALL TYPES OF DATA WHICH YOUR UNIT RECEIVES, PROCESSES/GENERATES, AND/OR SENDS **ELECTRONICALLY**: Please mark all that apply and write in data below not listed on right.

**Project Daily Diary**
Received☐ Processed/Generated☐ Sent☐

**Project Certified Payroll**
Received☐ Processed/Generated☐ Sent☐

**Project QA/QC Data**
Received☐ Processed/Generated☐ Sent☐

**Project Work Progress (Quantity Data)**
Received☐ Processed/Generated☐ Sent☐

**Project Work Progress (Schedule Data)**
Received☐ Processed/Generated☐ Sent☐

**Project Meeting Minutes**
Received☐ Processed/Generated☐ Sent☐

**Project Survey Data**
Received☐ Processed/Generated☐ Sent☐

**Other Data-1** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-2** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-3** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-4** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-5** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-6** ☐
Received☐ Processed/Generated☐ Sent☐

May we follow up with you at a later time for more detailed information? ○YES ○NO

**NCHRP SYNTHESIS 38-02**
**INFORMATION TECHNOLOGY for PROJECT DESIGN and CONSTRUCTION**

**SECTION 5: IT for OPERATIONS/MAINTENANCE FUNCTION**

What U.S. State Is Your DOT? ☐ Official Functional Unit Name: ☐

Name of Survey Respondent: ☐ Respondent's Job Title: ☐

Respondent's E-mail Address: ☐ Respondent's Phone Number: ☐

IN WHICH FORMAT ARE DATA **PRIMARILY RECEIVED** FROM OTHER UNITS?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

IN WHICH FORMAT ARE DATA **PRIMARILY PROCESSED/GENERATED** INTERNALLY?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

IN WHICH FORMAT ARE DATA **PRIMARILY SENT** TO OTHER UNITS?

○ Most always digital—Most never paper ○ Frequently digital—Seldom via paper ○ Approximately equal amounts of digital & paper ○ Frequently paper—Seldom digital ○ Most always paper—Most never digital

CHECK ALL TYPES OF DATA WHICH YOUR UNIT RECEIVES, PROCESSES/GENERATES, AND/OR SENDS **ELECTRONICALLY**: Please mark all that apply and write in data below not listed on right.

**Final Project Survey Data**
Received☐ Processed/Generated☐ Sent☐

**As-Built Quantity Data**
Received☐ Processed/Generated☐ Sent☐

**As-Built Drawings**
Received☐ Processed/Generated☐ Sent☐

**Pay Requests**
Received☐ Processed/Generated☐ Sent☐

**Project EEO Compliance**
Received☐ Processed/Generated☐ Sent☐

**Project SWP3 Documentation**
Received☐ Processed/Generated☐ Sent☐

**Project Certified Payroll**
Received☐ Processed/Generated☐ Sent☐

**Project DBE Compliance**
Received☐ Processed/Generated☐ Sent☐

**Other Data-1** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-2** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-3** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-4** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-5** ☐
Received☐ Processed/Generated☐ Sent☐

**Other Data-6** ☐
Received☐ Processed/Generated☐ Sent☐

May we follow up with you at a later time for more detailed information? ○YES ○NO

# APPENDIX B
# Results of Survey Questionnaire

**Process to Select States to Be Interviewed**

Step 1
Five functional areas were defined for each Department of Transportation: 1 - Planning, 2 - Design, 3 - Procurement, 4 - Construction, and 5 - Operations and Maintenance.

Step 2
Each functional area was requested to indicate the format used to "Receive", "Proceeding/Generate," and "Sent" data. The format options included: 1- Most always digital—Most never paper, 2 - Frequently digital—Seldom Paper, 3 - Approximately equal amounts of digital & paper, 4 - Frequently paper—Seldom Digital, and 5 - Most always paper—Most never digital.

Step 3
Each of the responses from the five functional areas was given the "Digital" values presented below. It is important to highlight that this was done to be able to quantitatively compare the answers among the states.

| | |
|---|---|
| 1 - Most always digital—Most never paper | → 100% Digital |
| 2 - Frequently digital—Seldom paper | → 75% Digital |
| 3 - Approximately equal amounts of digital & paper | → 50% Digital |
| 4 - Frequently paper—Seldom Digital | → 25% Digital |
| 5 - Most always paper—Most never digital | → 0% Digital |

Step 4
Each of the answers from the five functional areas from each state was multiplied by its corresponding "digital" value and added together. It is worth noting that if a division did NOT answer the survey a default value of "0" was given to the answers from the division.

Step 5
The top ranked based on "digital" values were short-listed for further investigation. Additionally, the input from the panel was used to decide the departments of transportation that were going to be interviewed.

See Table B1 and Figures B1 through B12 for survey results.

TABLE B1
WEIGHTED RESPONSES OF AGENCIES
TO DETERMINE MOST DIGITAL

| State | %of Digital based on Responses | % of Divisions Responses | % of DOT digital |
|---|---|---|---|
| AL | 67% | 20% | 13% |
| AK | 55% | 93% | 52% |
| AR | 58% | 80% | 47% |
| CA | 68% | 100% | 68% |
| CT | 66% | 53% | 35% |
| FL | 50% | 100% | 50% |
| GA | 53% | 100% | 53% |
| HI | 45% | 100% | 45% |
| IA | 50% | 20% | 10% |
| IN | 50% | 20% | 10% |
| KY | 78% | 100% | 78% |
| KS | 57% | 93% | 53% |
| MD | 48% | 93% | 45% |
| MI | 73% | 80% | 58% |
| MN | 48% | 100% | 48% |
| MT | 45% | 100% | 45% |
| NE | 42% | 40% | 17% |
| NH | 31% | 27% | 8% |
| NM | 68% | 100% | 68% |
| NY | 69% | 60% | 42% |
| OK | 42% | 100% | 42% |
| OR | 58% | 40% | 23% |
| PTA | 52% | 100% | 52% |
| SC | 68% | 100% | 68% |
| SD | 65% | 100% | 65% |
| TN | 75% | 40% | 30% |
| TX | 68% | 100% | 68% |
| VA | 81% | 60% | 48% |
| WI | 75% | 20% | 15% |
| WY | 43% | 100% | 43% |

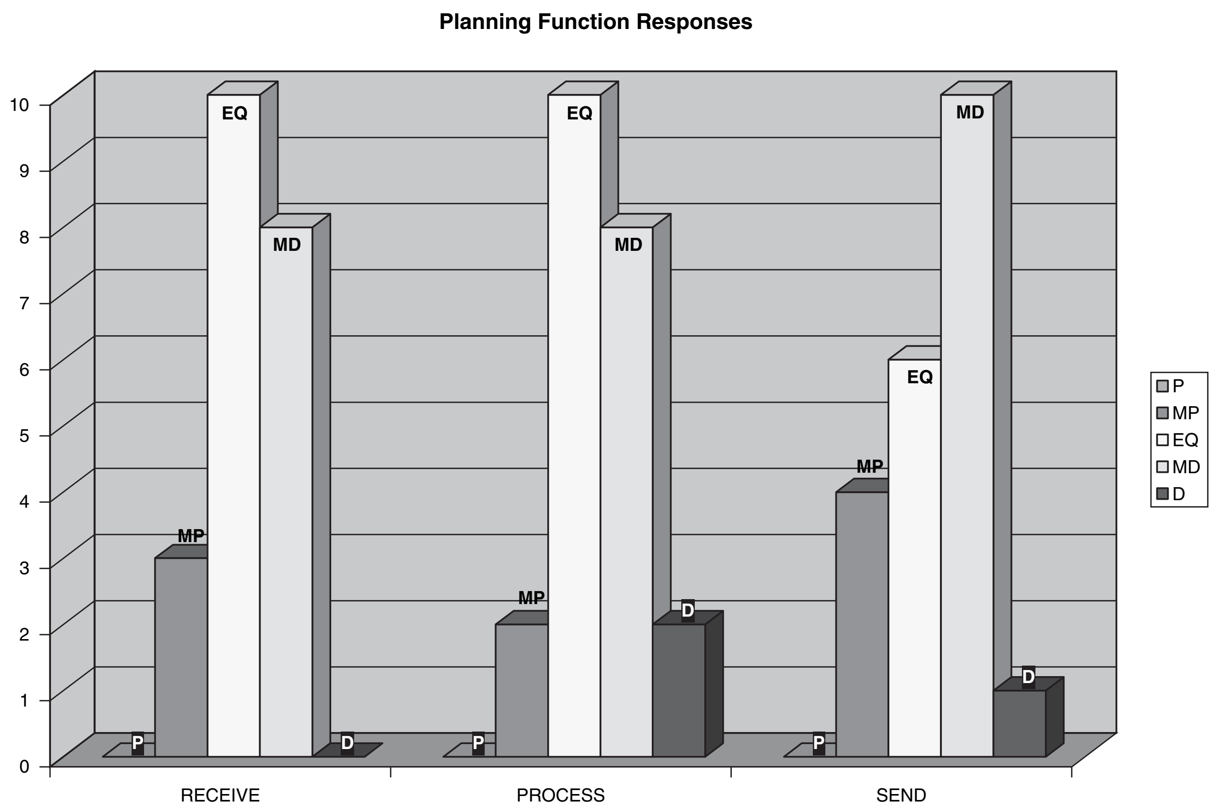


FIGURE B1 Data formats sent, processed, and received through the planning functional area. Note: P = paper, MP = mostly paper, EQ = equal amounts of paper and digital, MD = mostly digital, and D = digital.

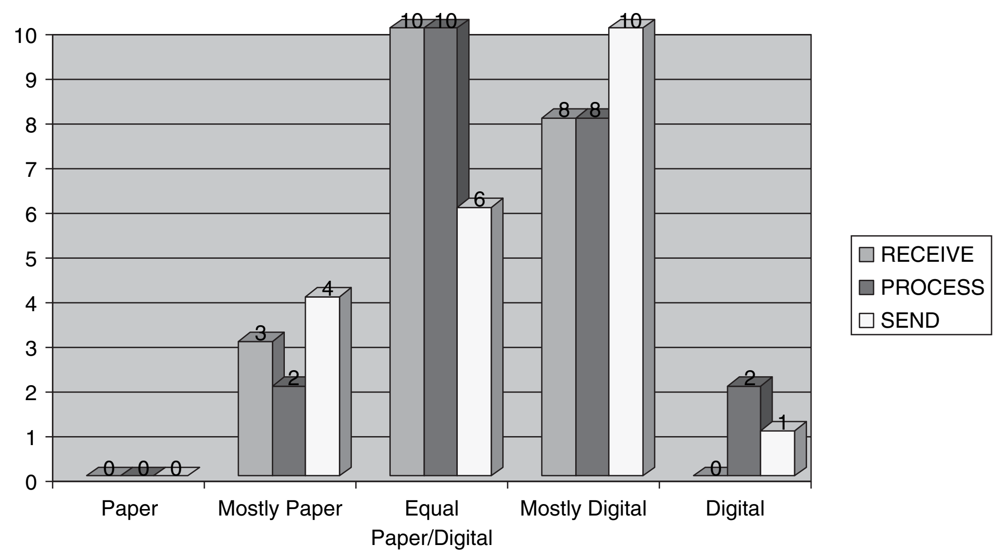


FIGURE B2 Data formats passing through the planning functional area.

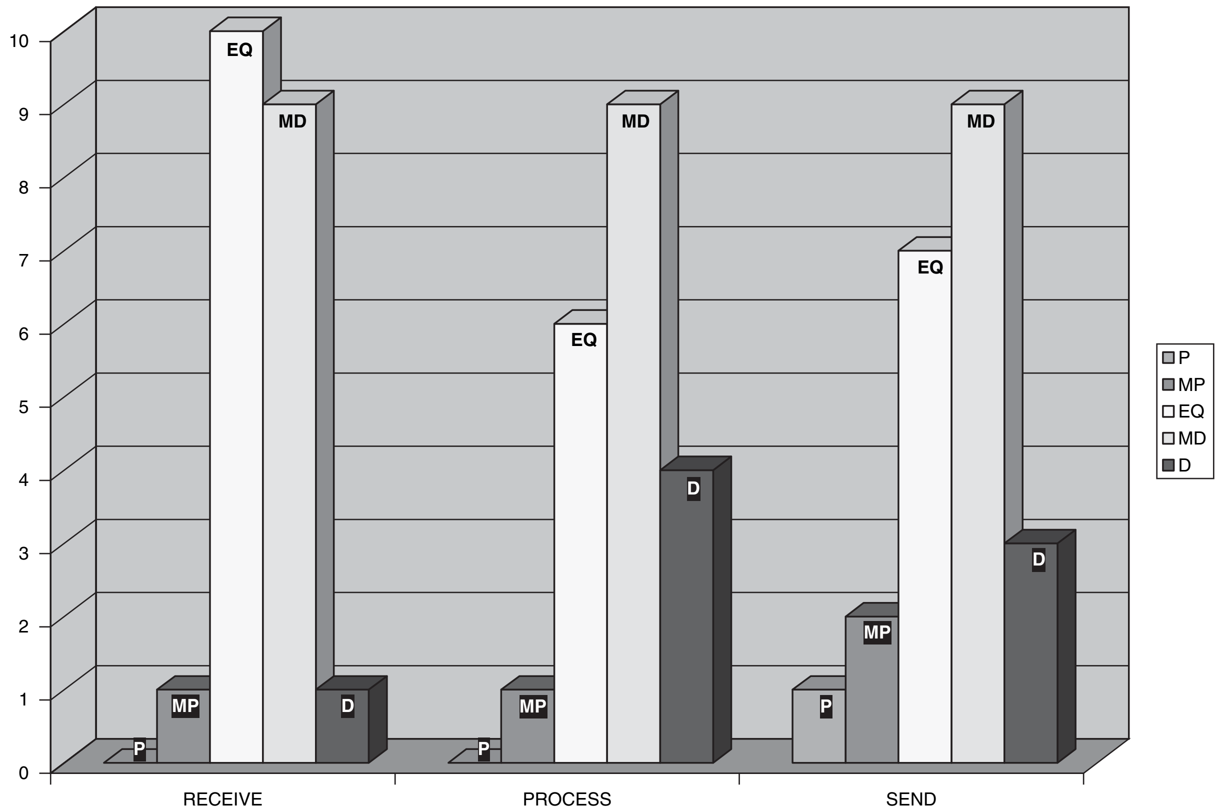


FIGURE B3  Data formats sent, processed, and received through the design functional area. Note: P = paper, MP = mostly paper, EQ = equal amounts of paper and digital, MD = mostly digital, and D = digital.

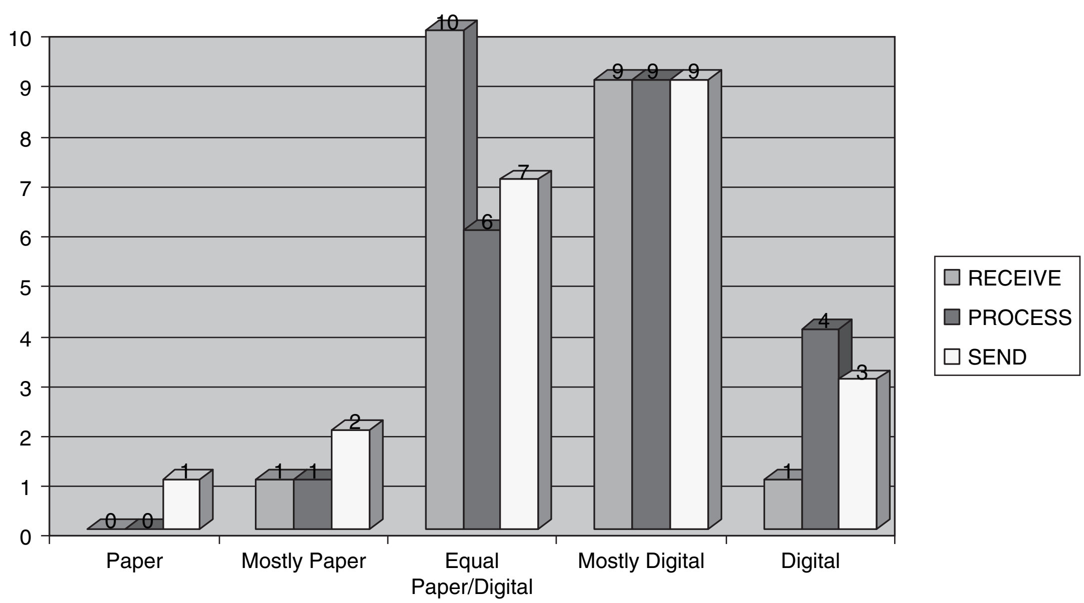


FIGURE B4  Data formats passing through the design functional area.

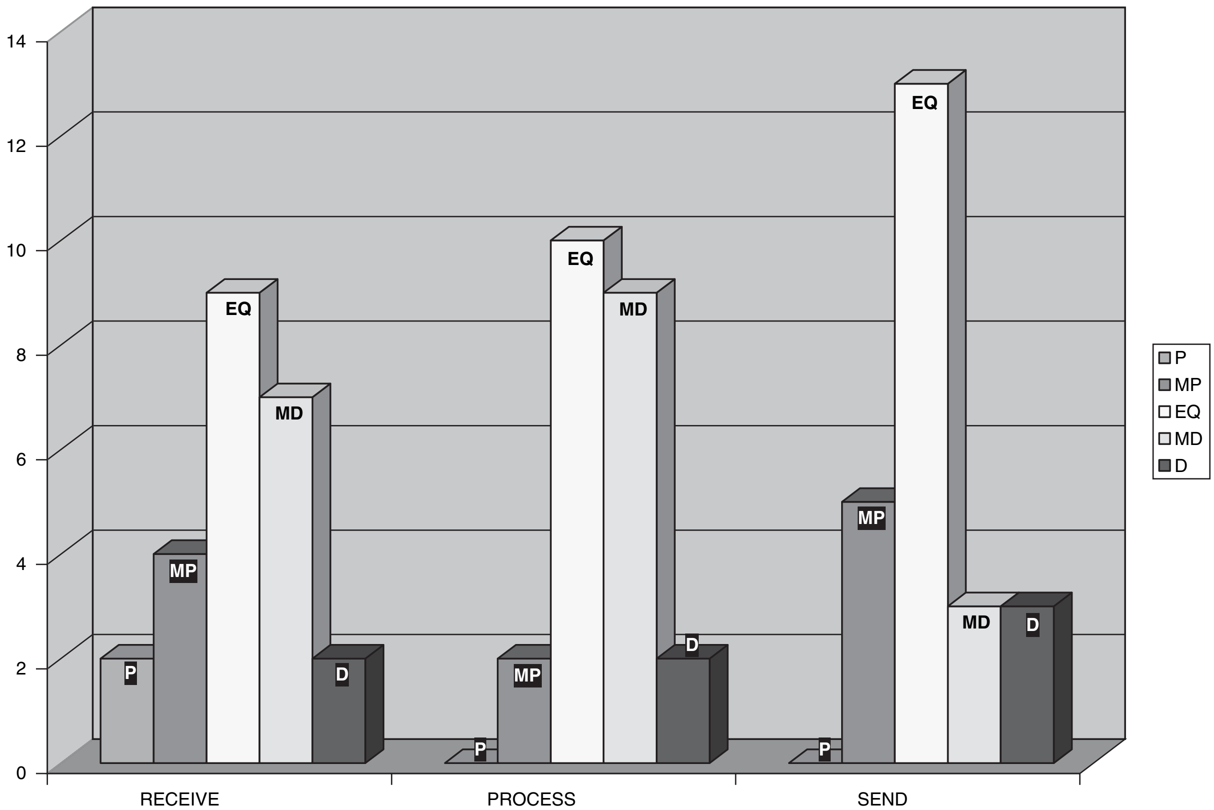


FIGURE B5 Data formats sent, processed, and received through the procurement functional area. Note: P = paper, MP = mostly paper, EQ = equal amounts of paper and digital, MD = mostly digital, and D = digital.

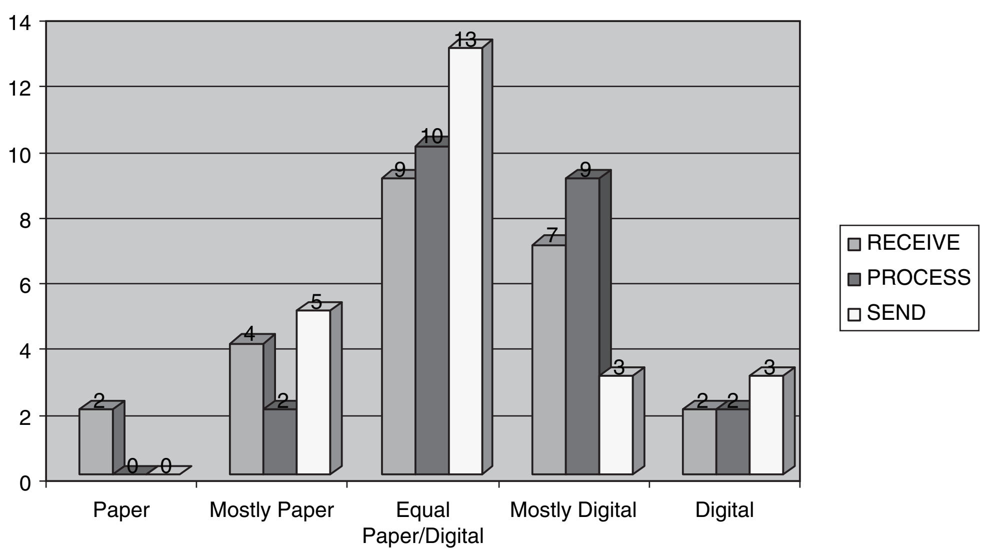


FIGURE B6 Data formats passing through the procurement functional area.

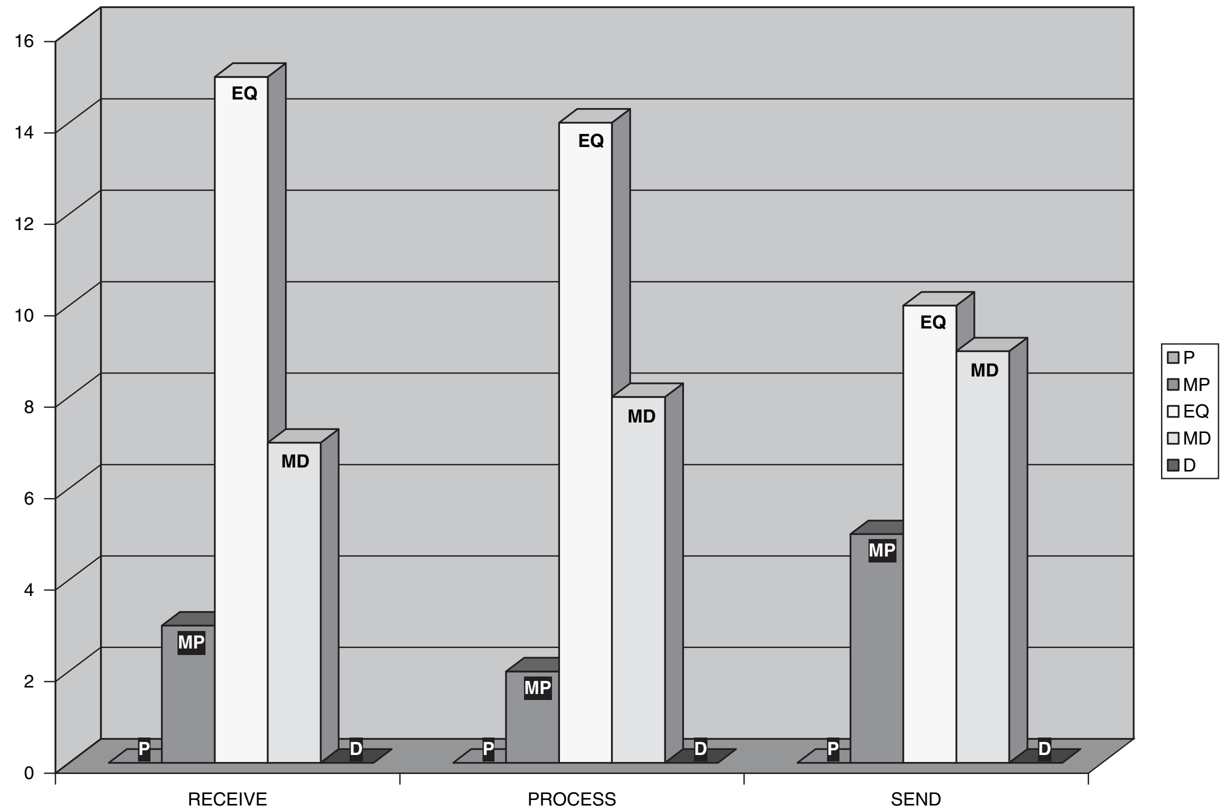


FIGURE B7 Data formats sent, processed, and received through the construction functional area. Note: P = paper, MP = mostly paper, EQ = equal amounts of paper and digital, MD = mostly digital, and D = digital.

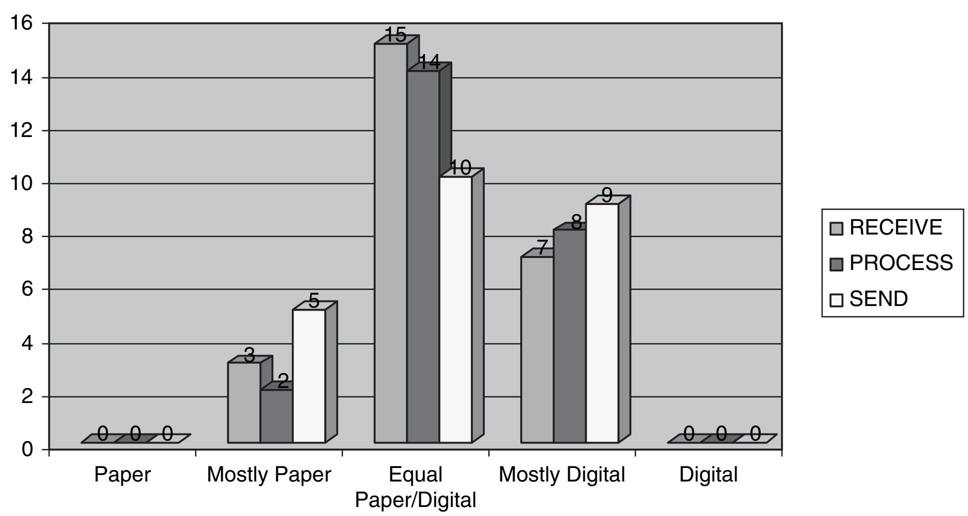


FIGURE B8 Data formats passing through the construction functional area.

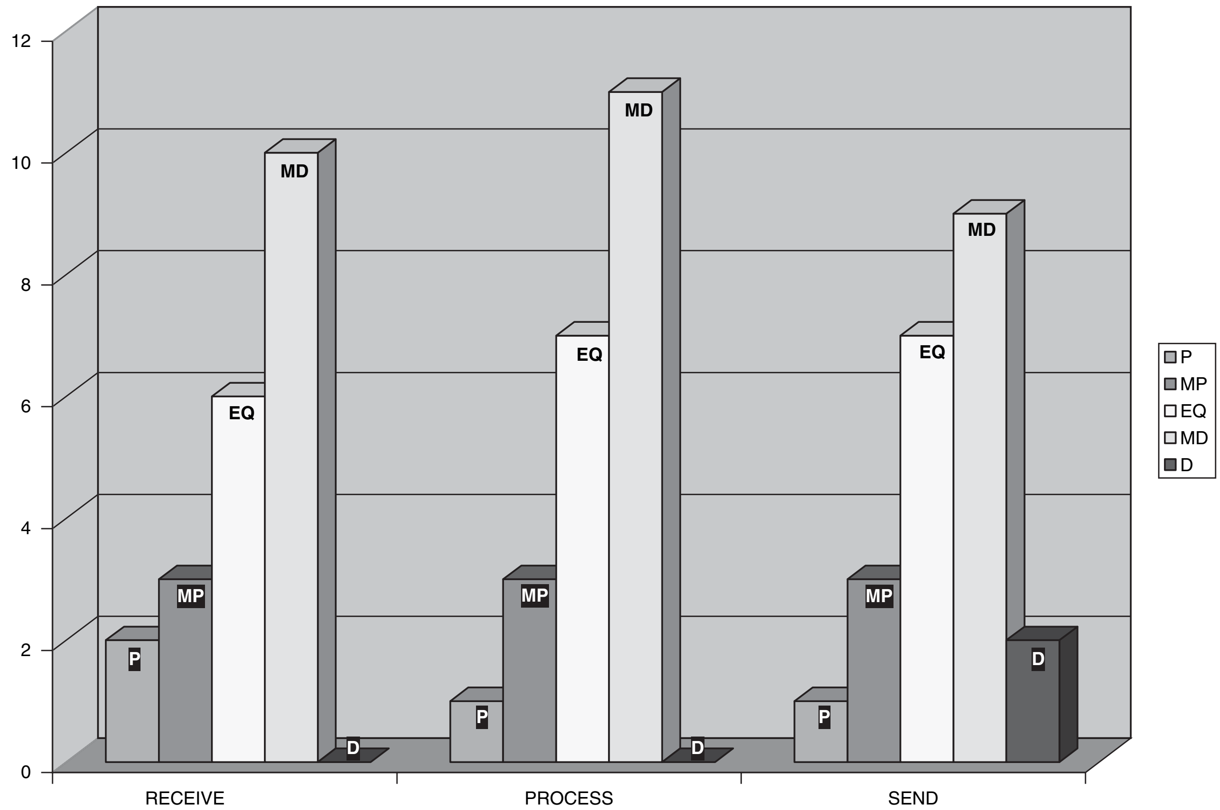


FIGURE B9 Data formats sent, processed, and received through the operations and maintenance functional area. Note: P = paper, MP = mostly paper, EQ = equal amounts of paper and digital, MD = mostly digital, and D = digital.

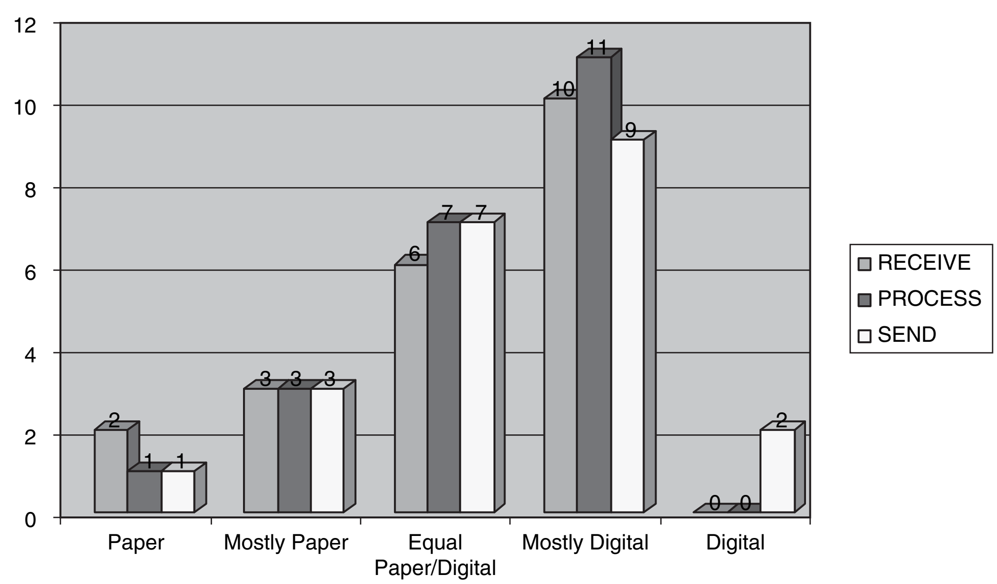


FIGURE B10 Data formats passing through the operations and maintenance functional area.

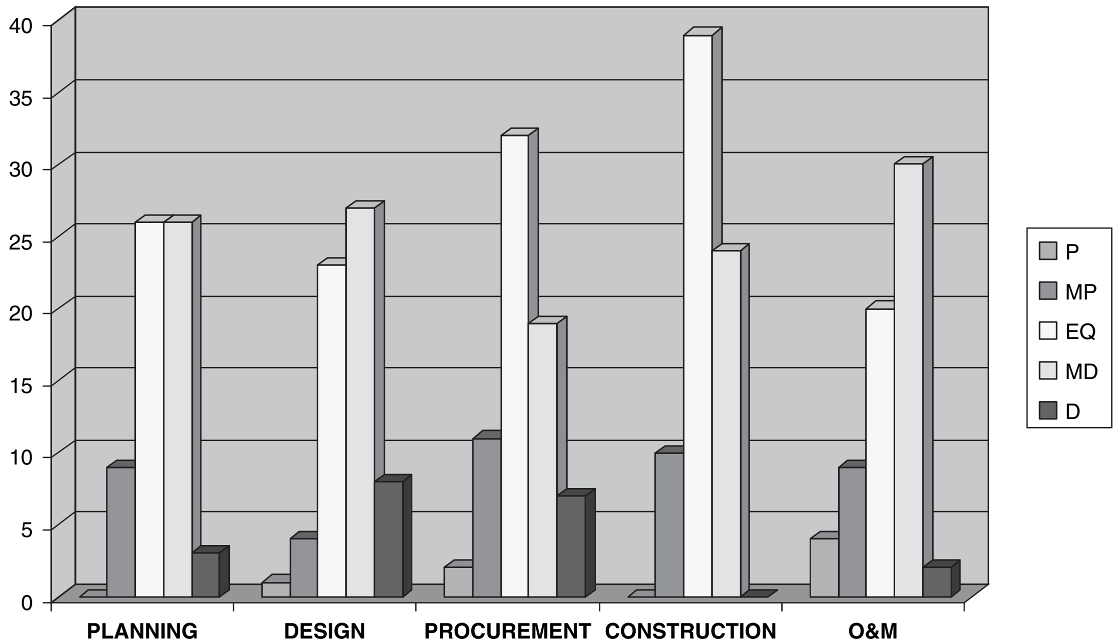


FIGURE B11 Comparison of paper-digital levels of all functional areas. Note: P = paper, MP = mostly paper, EQ = equal amounts of paper and digital, MD = mostly digital, and D = digital.

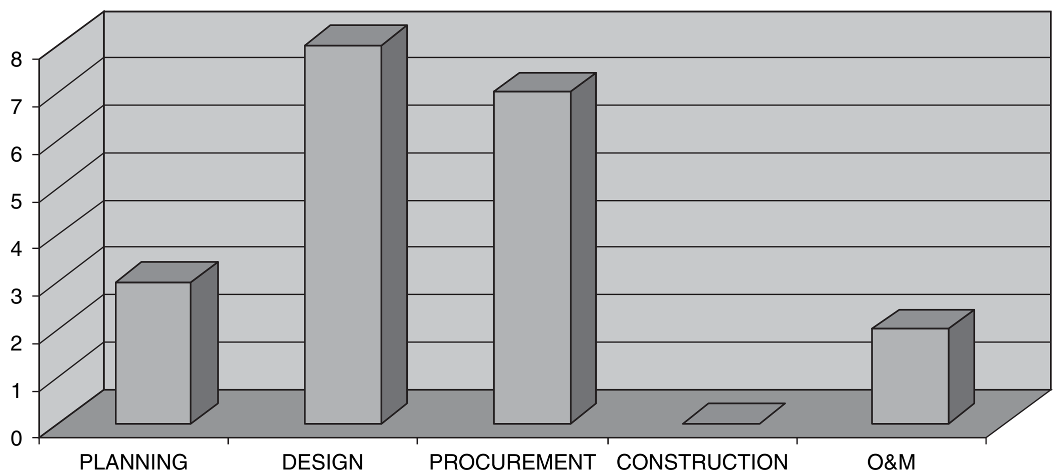


FIGURE B12 Purely digital survey responses by functional area.

# APPENDIX C
# Case Study Interview Form

The University of Southern Mississippi
School of Construction

NCHRP Project 20-5
Synthesis Topic 38-02

**Information Technology for Efficient Project Delivery**

State: ______________________________

Contact person: ______________________________

Contact phone: ______________________________

Interviewer: ______________________________

Date: ______________________________

---

**Q0.0 Functions**
What are the primary functions of this unit/division related to project delivery?
(*Function is defined as an activity that transforms inputs into outputs.*)

Function 1 ______________________________________________________

Function 2 ______________________________________________________

Function 3 ______________________________________________________

Function 4 ______________________________________________________

Function 5 ______________________________________________________

Function 6 ______________________________________________________

Function 7 ______________________________________________________

Function 8 ______________________________________________________

Function 9 ______________________________________________________

Function 10 _____________________________________________________

Function 11 _____________________________________________________

Function 12 _____________________________________________________

**Q1.0 Mechanism**
(*A mechanism is a person or machine that performs a functional activity.*)

Q1.1 What personnel are involved in performing this function?

___________________________ number of people _____
___________________________ number of people _____
___________________________ number of people _____
___________________________ number of people _____

Q1.2 Is software involved in Q1.1? Yes/No _______

If Yes, list software and hardware:

Software: _____________________ Hardware: ________________________
Software: _____________________ Hardware: ________________________
Software: _____________________ Hardware: ________________________

**Q2.0 Inputs**

(*Input is information or materials—i.e., data that are needed to perform a function.*)

Q2.1 List data and source that are needed:

Data: ___________________________
Source: ___________________________
Form of data: ___________________________ (*i.e., paper, digital, other*)
If digital, file format: ________________

**Q3.0 Control**

(*A control is a condition or circumstance that constrains a functional activity.*)

Q3.1 List any restrictions/limitations to the performance of this function and the source of the constraint:

Constraint: ___________________________
Source: ___________________________

Constraint: ___________________________
Source: ___________________________

Constraint: ___________________________
Source: ___________________________

**Q4.0 Outputs**

Q4.1 What is the product? (i.e., report, data to another unit)

Product: ___________________________
Target: ___________________________
Format: ___________________________ (*i.e., paper, digital, other*)
Product: ___________________________
Target: ___________________________
Format: ___________________________ (*i.e., paper, digital, other*)

Abbreviations used without definitions in TRB publications:

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