NCHRP

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

REPORT 481

Environmental Information Management and Decision Support System—Implementation Handbook

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 481

Environmental Information Management and Decision Support System—Implementation Handbook

BOOZ ALLEN HAMILTON
McLean, VA

AND

MICHAEL BAKER JR., INC.
Coraopolis, PA

SUBJECT AREAS
Planning, Administration, and Environment • Aviation • Public Transit • Rail • Freight Transportation

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TRANSPORTATION RESEARCH BOARD

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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.

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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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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration, U.S. Department of Transportation.

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FOREWORD

By Ronald D. McCready
Staff Officer
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This report contains the results of research into an environmental information management and decision support system (EIM&DSS) that can be applied to multimodal transportation planning, programming, project development, operations, and maintenance. This system was developed to meet the current and future needs of state Departments of Transportation (DOTs), Metropolitan Planning Organizations (MPOs), and other large transportation agencies. The EIM&DSS complies with international environmental management system standards (ISO 14001). Presented as a handbook, the report presents an eight-step process for initiating, developing, maintaining, and evolving a system of data and information management and decision support. The handbook demonstrates the feasibility and application of environmental information management and support throughout the major activities of a large and complex transportation agency. This report should be useful to practitioners in state DOTs and MPOs and to others concerned with planning, programming, and implementing transportation projects or managing the environmental mitigation actions and commitments of those agencies. The report will also be useful as an educational resource on the concepts, tools, and procedures for ongoing environmental stewardship within transportation agencies.

Environmental decisions regarding transportation planning, project development, construction, operations, and maintenance are among the most difficult facing transportation decision makers. Factors include the complexity of technical issues; the myriad laws and regulations at federal, state, and local levels; the costs and time required for environmental reviews; a wide and disparate range of interested parties who are potentially affected; a diversity of impacts and potential mitigation approaches; and the scarcity of precise environmental and other critical data. In addition, agencies are not consistent in executing their respective mandates. All these factors combine to confound efforts to achieve timely consensus, compromise, and effective decisions.

Current federal law requires state DOTs and MPOs to consider and reduce a wide range of environmental effects and impacts of transportation plans, programs, operations, and decisions. Furthermore, state DOTs are seeking transportation development decisions and operations that provide maximum mobility while protecting important human and natural environmental resources. To achieve these important objectives, agencies and practitioners need cohesive and integrated systems to facilitate rational decisions through cost-effective coordination of environmental information and data management that can be tailored to critical decisions. The EIM&DSS should facilitate collecting, organizing, analyzing, archiving, and coordinating the information and data necessary to support technical and policy transportation decisions. It should also foster integration of environmental considerations into transportation decisions regarding overall policy development, systems planning, corridor planning, capital priority programming, project planning and development, permitting, ongoing compliance requirements, and so forth. The primary users will be planners, project designers, project managers, environmental practitioners, operations managers, and facilities/maintenance forces. The EIM&DSS must be capable of analyses supporting risk management assessments and benefit/cost analyses associated with transportation projects, the impacts of existing transportation construction and maintenance practices, and effective project streamlining.

Under NCHRP Project 25-23, "Environmental Information and Decision Support System for Transportation," Booz Allen Hamilton, Inc., of McLean, Virginia, developed a concept for establishing environmental information management and decision support for transportation plans, programs, projects, operations, and maintenance activities. Presented as a handbook, this report provides practitioners with a step-by-step approach for implementing the EIM&DSS within a wide range of organizational settings and applications. As such, the handbook provides a strong foundation for the development, tailored application, and ongoing implementation of effective environmental management and stewardship in a transportation setting. Reference documentation supplied as part of the research team's final report is available on line as *NCHRP Web Document 55*.

CONTENTS

AUTHOR ACKNOWLEDGMENTS

Booz Allen Hamilton was the contractor for the project and Michael Baker Jr., Inc., was the subcontractor.

The co-principal investigators for NCHRP Project 25-23 were William A. Hyman, Senior Associate, and Judi Dotson, Principal, both of Booz Allen Hamilton. Other Booz Allen Hamilton staff who made significant contributions to the project were Zongwei Tao, Amy Rubin, and Benjamin Bjorge, all Associates. Kathy Sopenski, Planning Manager, was the primary contributor to the project from Michael Baker Jr., Inc.

The research team wishes to acknowledge the valuable guidance of the NCHRP Project 25-23 panel and the strong support of the NCHRP Program Officer, Ron McCready.

DEDICATION

This report and the underlying research is dedicated to Ezra Aviles who was a member of the NCHRP Project 25-23 Panel and worked for the Port Authority of New York and New Jersey. He perished in the terrorist attack on the World Trade Center. Ezra was a strong believer in the environmental benefits and improved transportation decision making that would result from developing and implementing an effective environmental management system. As a result, he was a strong supporter of the project. His enthusiasm and talent cannot be replaced.

SUMMARY

The National Cooperative Highway Research Program (NCHRP) initiated Project 25-23 to respond to the need of state transportation agencies and metropolitan planning organizations (MPOs) for systems to manage environmental information and support decision making. The objective of the project was to develop a concept and implementation approach for an Environmental Information Management and Decision Support System (EIM&DSS) that addresses all levels of decision making—planning, programming, project development, operations, and maintenance—for all modes of transportation. The outcome of the project is this handbook, which describes the concept for the EIM&DSS and provides guidance to state transportation departments and MPOs on developing and implementing such a system.

The EIM&DSS is best understood as a DSS that draws upon an EIM system to provide decision makers with the information and analysis necessary to choose from various alternatives and to track progress on achieving environmental goals. The goals are established within a framework of the International Organization for Standardization (ISO)—the ISO 14001 standard for Environmental Management Systems (EMS) (see Figure 1).

More specifically, this handbook defines an EIS&DSS as follows:

> *. . . any system that strives to provide decision makers involved in planning, programming, project development, operations, and maintenance for any mode of transportation with the right information and analysis, in the right format, and at the right time to make specific decisions and to continually improve the outcomes of the agency's activities, operations, products, and services when measured in terms of transportation, environmental, social, cultural, and economic factors.*

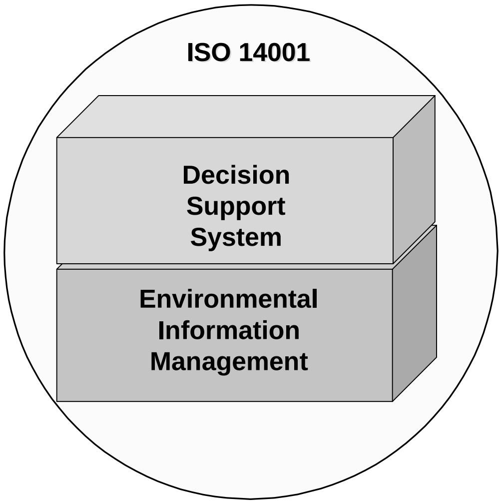


Figure 1. The EIM&DSS in Relation to ISO 14001

EXAMPLE APPLICATIONS

The EIM&DSS is rich in functionality and will benefit a wide variety of decision makers, managers, analysts, and stakeholders. The types of applications and their corresponding benefits are described more fully in Table 1.

Table 1. Applications of the EIM&DSS

Use Case	User	Application
Environmental Performance and Public Reporting	Chief Executive Officer and Administrators	Examining an environmental report card that is shared with the public on the Internet. Identifying progress in achieving targets for environmental outcomes established through a process compliant with the ISO 14001 standard for environmental management systems.
Compliance with Stewardship and Formal Commitments	Project, Area, and District Managers; Environmental Bureau	Obtaining information on the compliance status of all commitments to stakeholders—ranging from voluntary initiatives for enhancing the environment to satisfying legal or permit requirements. Identifying how the responsibility for meeting commitments changes from phase to phase.
Reduced Time and Costs of Workflow	Managers, Analysts, and Regulatory Agencies	Accessing workflow diagrams and metrics on duration and costs of environment-related business processes. Identifying opportunities for streamlining that save time and money. Also, using electronic approvals to save processing time for steps requiring review and signatures.
Environmental Impact Statement	Planners, Designers, Engineers	Querying an integrated database, a Geographic Information System (GIS), and a document management system that has all the information to analyze alternatives and manage public involvement for an EIS.
Categorical Exclusions	Head, Environmental Bureau	Focusing limited environmental analysis resources on actions requiring an Environmental Impact Statement (EIS) or an environmental assessment. Using the EIM&DSS to apply criteria for categorically excluding no-or low-impact actions from the need to perform more detailed environmental analysis. Document decisions regarding categorical exclusions.
Best Management Practices	Transportation Managers (any mode)	Accessing an EIM&DSS web page that provides information, training materials, and benchmarking data on best management practices for environmental issues related to construction, maintenance, and operations.
Air Quality Conformity Analysis	Regional and State Planners	Rolling up current and projected air quality emissions for various types of transportation activity and projects that form the Long-Range Plan and the Transportation Improvement Program (TIP) to assess whether total emissions exceed emission budgets.
Collaborative Design	Agency Staff, Citizens, Regulators, Environmental Groups	View alternative location and design concepts in 2D, 3D, or even virtual reality. Relevant transportation, environmental, social, economic, and cultural impacts are displayed for each alternative. Citizens can influence design concepts and obtain feedback regarding environmental impacts in nearly real time.
Bridge Program Analysis	Bridge Program Manager	Determining current and projected environmental impacts and costs of current and future bridge maintenance and improvement actions for the thousands of bridges on a highway network.
Site Audits	Facility Maintenance Engineer	Preparing for an environmental audit of a maintenance facility. Accessing the audit checklist, progress report, key issues, environmental data, and "To Do" list of next steps.
Water Quality Analysis	Environmental Analyst	Exploring how transportation activity affects the ecology of a watershed by viewing maps in the GIS, defining alternative scenarios, and exercising a wide variety of in-house and external simulation models on the Internet.
Data Mining	Anyone authorized	Finding specific environmental, social, economic, and cultural data and determine the source, coverage, collection date, completeness, and accuracy of such data.

CUSTOMER-DRIVEN REQUIREMENTS ANALYSIS

The concept for the system was developed using a top-down, customer-driven approach and involved nearly all the states and numerous MPOs. Business processes that the EIM&DSS needs to support were mapped and documented, on the basis of input from the states and MPOs. This highly inclusive, participatory approach resulted in substantial guidance and buy-in from potential users of an EIM&DSS. Elements of the approach follow:

- Over 150 use cases (ways in which different users would be expected to interact with or use the system) were developed and cover all levels of decision making.
- Joint Application Development (JAD) sessions were conducted in four regions of the United States. Participating states were Maryland, Virginia, Wisconsin, California, and Washington.
- State Departments of Transportation (DOTs) provided many documents representing exemplary types of environmental analysis pertinent to different levels of decision making.
- A total of 27 state DOTs and 57 MPOs responded to survey questions regarding current and future information and analytical needs for an EIM&DSS.
- Copies of the Interim Report were sent to all state DOTs and numerous MPOs for review and comment. In addition to providing feedback, several requested additional information they could use as input into their current efforts to develop an EMS.

VIEWS OF THE SYSTEM

This handbook sets out the concept for the EIM&DSS by providing various views of the system. These views are as follows:

- Different Views of the User Interface—
  - Main Module View—A view of the main screen of the EIM&DSS;
  - Use Case and Enterprise View—The relationship between specific use cases, Geographic Information System (GIS), and the enterprise database;
  - GIS-Centric View—The GIS interface as a central way to access, interpret, and analyze information; and
- Business Process View—A view of the system that shows how it supports a wide variety of business processes of state DOTs and MPOs;
- Functional Views—
  - Diagram of Functional Elements—Shows the functional building blocks of the system;
  - Layers of the EIM&DSS—Shows layers of the system consistent with an evolution from an unorganized information management system to a highly integrated decision support system able to support collaborative decision making;
  - Role of Location Referencing—Shows the central role of location referencing and linkages to all key functional elements of the EIM&DSS;

- ISO 14001 View—Describes the requirements of the ISO 14001 standard that the EIM&DSS needs to satisfy;
- Technical Architecture View—Presents the main components of the EIM&DSS technical architecture for a centralized enterprise system;
- Object View—Shows key elements of an object model appropriate to a highly distributed EIM&DSS; and
- Database View—Describes a high-level entity relationship diagram that is a starting point for a detailed database design.

OVERVIEW OF SYSTEM CONCEPT

The main module view, representing the opening screen for accessing the system, provides excellent insights into the capabilities of the EIM&DSS. The opening screen is shown in Figure 2.

Each button on the screen represents a key type of functionality and, in many cases, the buttons correspond to important modules:

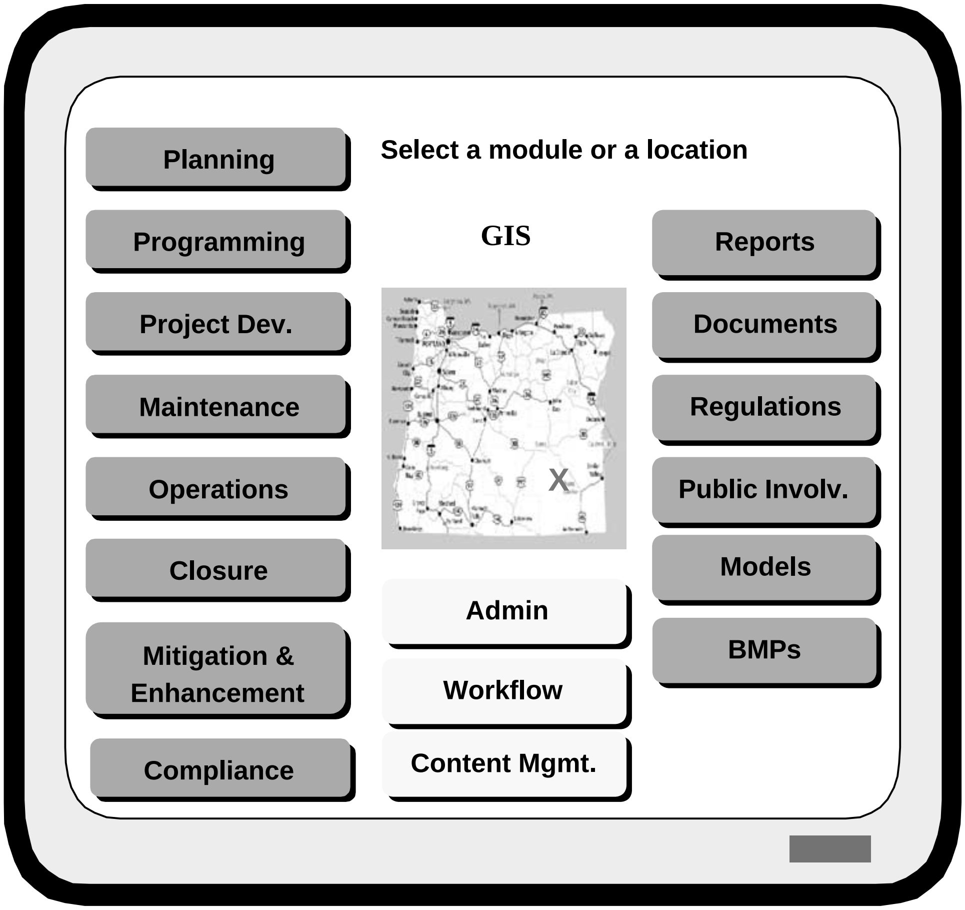


Figure 2. Main Screen of the EIM&DSS

- **Planning.** Clicking on this module lets users display a copy of any department plan and its contents, including corridor plans, strategic plans, long-range plans, and pollution prevention plans. The user would be able to obtain information about the status of the plan, its project and program composition, proposed funding sources, alternatives considered, and any plan-level environmental, social, cultural, and economic assessment of alternatives.

- **Programming.** The programming module gives the user access to single- and multi-year transportation programs and supporting analysis and data. Transportation Improvement Programs (TIPs) would be accessible, and so would analysis of the conformity of the TIPs with national ambient air quality standards. Details of the transportation, environmental, social, cultural, and economic impacts of underlying projects and subprograms could be viewed in full or in summary form.

- **Project Development.** This module would allow a user to select a project from a list of all projects in the department or MPO. Alignments from the computer-aided drafting and design (CADD) system would be accessible. Project development information would include project boundaries, description, alternatives, schedule, status, permit requirements and regulatory compliance, as well as direct, indirect, secondary, and cumulative impacts.

- **Maintenance.** EIM&DSS users will be able to access a broad range of environmental data and analysis on the maintenance of different modes. Maintenance information will cover infrastructure, facility, vehicle, and equipment maintenance. In the case of highway maintenance, information will be available on maintenance activities such as pavement and bridge repair, sign work, striping and markings, guardrail repair and replacement, drainage work, vegetation management, rest area maintenance, and snow and ice control.

- **Operations.** This module gives the user access to environmental information and decision support inputs for operations. Operations include real-time traffic management involving Intelligent Transportation Systems (ITS), emergency response, and daily passenger and freight operations such as subways, airport terminals, and port activity. Operations may include traffic-related activities that are sometimes included in the maintenance program such as installation, repair, and replacement of signs as well as striping and marking operations.

- **Closure.** This area addresses all stages of the lifecycle of transportation facilities, including closures, decommissioning, and transfers of facilities from one jurisdiction to another.

- **Mitigation and Enhancement.** Here, the user could learn about mitigation and enhancement actions addressed in plans or programs—or pertinent to projects, operations, or maintenance.

- **Compliance.** A user will be able to obtain information on compliance with environmental stewardship initiatives and regarding regulations, permits, mitigation and/or enhancement requirements, and so forth. Compliance information will be accessible in many convenient ways, including by plan, program, project, operations, maintenance, administrative unit, and location.
- **GIS.** The user will be able to click on a digital map and access GIS capabilities, including spatial display and analysis of data, dynamic segmentation, and the ability to access thematic geographic data.
- **Administration.** This button lets system administrators manage the EIM&DSS. It will incorporate data rights and security procedures.
- **Workflow.** The EIM&DSS will include business process flow diagrams for all levels of decision making and for related data collection, storage, and retrieval. It will be possible to establish the steps of an approval process and electronically send requests for and receive approvals. The workflow management system will apply to business processes that occur entirely within an organization and those that require interaction and approval with other agencies, including environmental regulatory agencies.
- **Content Management.** This module provides information to ensure that data items entered into the EIM&DSS are worth collecting and current. The module shows who is responsible for each type of data and provides metadata (data about data). Metadata includes information on the source, geographic coverage, time period, completeness, and accuracy of the data.
- **Reports.** The user will be able to access a wide variety of standard reports and easily construct ad hoc reports using simple forms and report construction tools.
- **Documents.** This button lets the user search, manage, and retrieve all documents stored in the EIM&DSS database or other databases that are part of a distributed system. Documents will include policies and procedures, guidelines, manuals, handbooks, training materials, reports, Material Safety Data Sheets (MSDSs), memoranda of understanding, compliance agreements, and contracts.
- **Regulations.** This gives users access to current federal and state laws and regulatory information, including regulatory data in the EIM&DSS database from regulatory agencies and from public- and private-sector information services.
- **Public Involvement.** A user will be able to retrieve all public involvement plans, records, and input regarding a plan, program, project, or maintenance or operations activity. The public will be able to submit comments and view responses on the Internet.
- **Models.** This module presents a menu of models, DSSs, and management systems. Models from the EIM&DSS can be used (provided an application

program interface or other data transfer mechanism has been established to provide input data).

- **Best Management Practices (BMPs).** Here one can access information on environmental BMPs related to each level of decision making.

IMPLEMENTATION STEPS

This handbook sets out recommended steps, shown in Figure 3, for implementing the EIM&DSS concept. This concept must be implemented in phases, with each phase focused on one or more building blocks.

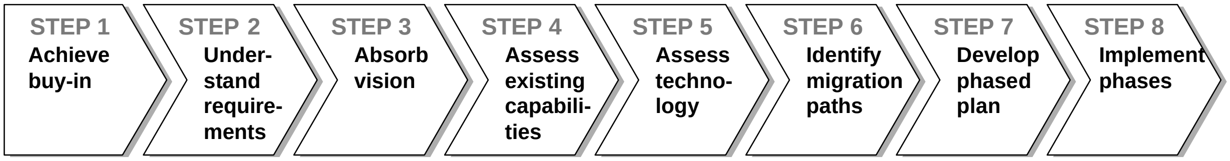


Figure 3. Summary of Implementation Steps

The eight implementation steps described in this handbook should be followed methodically to ensure that the resulting EIM&DSS achieves the agency's vision. The development process is meant to be iterative, with each agency assessing its needs and technical environment and implementing only the building blocks that meet its goals. An assessment of costs and benefits is an essential part of the process.

Building blocks should generally be implemented in the order listed in Table 2, although some may be implemented in a different sequence. For example, the BMP portal could be implemented earlier if identification of BMPs did not depend on performance

Table 2. Order for Implementing Hardware and Software Building Blocks of EIM&DSS

Major Components	Building Blocks
EIM	1. Office suite software with word processing, spreadsheet, and presentation capabilities 2. ODBC relational / object database software 3. GIS software and location referencing 4. CADD software 5. Content management system and metadata 6. EIM relational database tables 7. Communications software and hardware 8. Workflow management system
DSS	9. System integration—environmental models 10. System integration—transportation management system and models 11. Decision support (performance measures) 12. Best management practices portal

measurement. Also, the decision support (performance measurement) building block could be partially implemented with the EIM relational database management system (RDBMS) tables, so that some decision support capabilities could be provided in an earlier implementation phase. In general, however, the first building block provides the foundation for the second, the second provides the foundation for the third, and so on.

Agencies and/or stakeholder groups can assess the usefulness of each building block of the system in turn by asking: Do we have this? If the answer is “yes,” then they move on to the next block. If the answer is “no,” then the next question is: Do we want this? If the answer is “yes,” then the building block becomes part of the implementation.

Some of these building blocks may fit the agency’s goals—but not the budget or the timeframe for implementation. Systems should be designed with the flexibility to allow for enhancements when funds and time become available.

As each agency works through the implementation process, it will find that there are different stepping stones and alternative migration paths toward realization of the full vision for the EIM&DSS. Figure 4 shows the main paths toward achieving the full vision.

The technology assessment performed in developing this handbook suggests that agencies will first develop an EIM with an integrated GIS, CADD system, and relational/object database. They will then add elements of the DSS. Along the way, a fundamental choice will need to be made regarding the extent that the system will be a centralized or a distributed system. Because of the growing ability to access secure data and applications anywhere on the Internet, it is projected that technology advances will strongly favor a distributed system in the next 10 to 20 years, and perhaps even today. Indeed, the

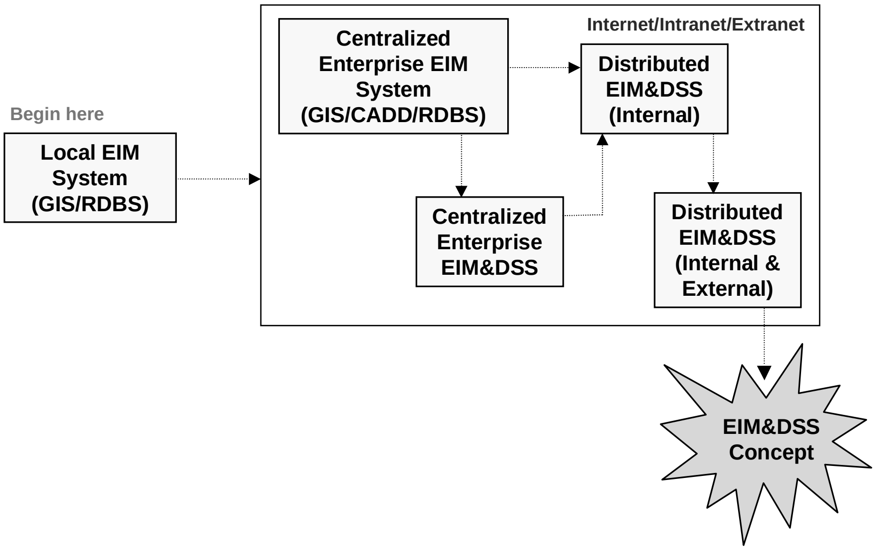


Figure 4. Alternative Migration Paths

concept for the EIM&DSS is intended to be durable—and support an evolving system with at least a 10-year life.

CONTENT MANAGEMENT

There are no technical barriers to developing the EIM&DSS. Even the most challenging aspects—integration of various management systems and simulation models—are technically feasible, though time-consuming and not without cost. However, system implementation will fail if not enough attention is given to the following issues:

- Is the value of the data and information put into the system great enough to warrant collecting it and maintaining it over its life cycle?
- Are the data complete and accurate enough for the purposes intended?
- Is responsibility clearly assigned to individuals for collecting and updating each category of data in the system?
- Can potential users of the data access metadata to determine the source, coverage, and quality of the data, and the person responsible for the data?

The EIM&DSS includes a content management system to ensure that these types of issues are addressed. A content management system needs to be implemented as soon as the basic database for the EIM component of the system is designed. If a strong content management system is implemented, it will help ensure implementation success.

INTRODUCTION

This handbook provides a vision, a concept, and alternative implementation strategies for an Environmental Information Management and Decision Support System (EIM&DSS) that can evolve to meet the 21st century needs of transportation organizations. The EIM&DSS concept supports planning, programming, project development, operations, and maintenance for all modes of transportation. Alternative implementation strategies account for the wide range of approaches to transportation and environmental management, existing systems, and databases found in U.S. state and Canadian provincial transportation departments and regional planning organizations. The EIM&DSS concept also is useful for regulatory and environmental resource agencies as well as for private firms, especially those that perform transportation and environmental activities under contract or in public-private partnerships with public-sector transportation organizations.

The EIM&DSS concept fully takes into account the worldwide trend of government and private-sector organizations toward adopting environmental management systems (EMSs). The EIM&DSS concept is responsive to rapid technological change that can support environmental management, centralized and decentralized decision-making, and various data collection, storage and dissemination systems.

The EIM&DSS concept and alternative implementation strategies were the result of requirements analysis based on the following:

- Current and future information requirements;
- Current and future analysis requirements;
- Functional requirements;
- Different ways users will need to interact with the system (use cases);
- Business processes that need to be supported;
- An analysis of data entities and their attributes that can serve as the basis for designing a relational database;
- An object-oriented model that can support highly distributed processing in a rapidly evolving Internet environment; and

- A technological assessment to ensure the EIM&DSS will work with existing and emerging technology and have a life cycle of 10 to 20 years.

These requirements were established using a customer-driven, top-down process that sought input from those responsible for dealing with environmental issues in planning, programming, project development, operations, and maintenance for various transportation modes. Current and future information and analysis needs and functional requirements came partly from survey questionnaires administered to all states, Canadian provinces, and metropolitan planning organizations (MPOs) and by conducting joint application development (JAD) sessions involving numerous state departments of transportation (DOTs) in four regions of the United States.

Requirements were also established by synthesizing a "best practices" model for an EIM&DSS from the literature on EMS and decision support systems found throughout the world and by performing an assessment of current and emerging technologies that build on the new environmental technologies as presented in NCHRP Project 25-22, "Technology To Improve Consideration of Environmental Concerns in Transportation Decisions."

THE MANDATE FOR ENVIRONMENTAL STEWARDSHIP

Making transportation decisions in an environmentally sensitive manner is among the most challenging issues the public and the private sector face. Government policy makers recognize there is a need for a balanced approach to decision making. Transportation management must support economic growth through improvement in the mobility, accessibility, safety, and reliability in the movement of goods and people while being sensitive to environmental, social, cultural, and equity issues. Also it is important to achieve the proper balance between capital improvements and system preservation. Transportation improvements are often very difficult to make. Although there may be strong justification and political support for a project or system enhancement, often there is great opposition if it directly or indirectly affects the property of numerous households or businesses.

Because of fragile ecosystems, declining diversity, various types of pollution, and the need to combat the risk of global warming, there is enormous political pressure to protect and enhance the environment. Not only do public interest groups and environmental activists exert pressure, but also there is a growing consensus among the body politic that finding ways to minimize adverse effects and improve the environment must be a part of transportation decision making.

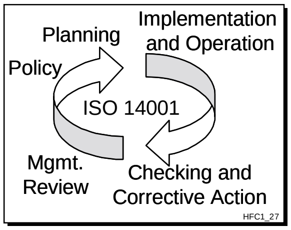
Environmentally sensitive transportation decision making is becoming a business necessity for many firms in the global economy. There is increasing demand for “greener” products and services. There is growing recognition that innovation driven through simultaneous achievement of environmental, energy consumption, and business goals can boost profits and help achieve strategic advantage. Worldwide competition in price and product attributes, including reusability and the ability to recycle, have made continuous quality improvement a permanent feature of successful corporations.

Ford and General Motors, like many other Fortune 500 Companies require their suppliers to have an ISO 14001-compliant Environmental Management System

Taken all together, these trends are making environmental stewardship an imperative of transportation organizations in the public- and private-sectors. There is a great need for appropriate tools that will lead to better decision making. To an increasing degree, business and government alike are framing decision making within a context of measurable performance that includes continuous assessment of environmental outcomes. Consequently, many firms are implementing environmental management systems and certifying that they comply with requirements of the International Organization of Standardization (ISO)(see sidebar). These requirements are referred to as ISO 14001. Private- and public-sector organizations throughout the world have implemented tens of thousands of environmental management systems certified as being compliant with ISO 14001. Most of these implementations have occurred in Japan, Europe and the United States. Many large corporations throughout the world are requiring that their suppliers certify they have an ISO 14001 EMS. Similarly many government transportation agencies throughout the world are implementing ISO 14001-compliant EMSs.

WHAT IS AN ENVIRONMENTAL MANAGEMENT SYSTEM?

The concept of an environmental management system is an outgrowth of the quality improvement movement. An EMS is a framework for continuously improving measurable environmental outcomes that result from organizational decision making. Outcomes are defined as the results, effects, or consequences of making decisions and taking actions.



More specifically, the ISO 14001 standard for an EMS consists of the five main elements illustrated in the sidebar figure to the right and addressed as part of a continuous improvement process:

1. **Environmental Policy—**Establish an environmental policy that provides for compliance with laws and regulations and for continuous improvement regarding pollution prevention and attainment of targets and objectives in a manner appropriate to the nature, scale, and environmental impacts of the concerning environmental matters, and periodically conduct an audit of the environmental management system.

2. **Planning—**Plan so as to address all environmental aspects of the organization's activities, operations, products, and services that affect the environment. Establish objectives and targets consistent with policy and to achieve pollution prevention for each function and level within the organization. Establish environmental management programs, including roles and responsibilities, resources (e.g., labor, equipment, material, and financial), time frame, and schedule for achieving the environmental targets and objectives.

3. **Implementation and Operation—**Monitor and measure environmental performance, track the effectiveness of controls, and assess progress in achieving environmental objectives and targets.

4. **Checking and Corrective Action—**Address non-conformance, or take preventive or corrective actions, and maintain records.

5. **Management Review—**Have a process to assess the suitability, adequacy, and effectiveness over time of the EMS, and address the needs for changes to policy, objectives, and other elements of the system in light of the commitment to continuous improvement.

NEEDS OF DOTs EXCEED THOSE OF AN ISO 14001 EMS

State DOTs and other transportation agencies have concluded that an EMS compliant with the ISO 14001 standard is not sufficient to meet their decision-making needs. State DOTs, Canadian provincial transportation departments, and MPOs have been in the forefront of performing environmental analysis since the Enactment of the National Environmental Policy Act (NEPA) in 1968 and the 1970 Clean Air Act. Larger transportation agencies already have substantial environmental databases, a geographic information system (GIS), integrated computer-aided drafting and design (CADD) system, and various decision support tools for various combinations of transportation and environmental decision making. **An EIM&DSS needs to build on existing information management and decision support systems that are already effectively serving transportation agencies.**

These environmental analysis and decision support systems need to support all levels of decision making and different modes of transportation, including intermodal connections. Indeed, transportation agencies require many types of analysis. Some typical examples are as follows:

- An examination of a broad range of social, economic, and cultural factors, in addition to pure environmental issues;
- An examination of network-level impacts;
- Assessments of secondary and cumulative impacts;
- An evaluation of pollution transport and fate over time;
- A capability to address various constraints, such as emission and financial budgets;
- The ability of the public and private sector to share information, designs, and analysis; and
- The need to support a wide range of public input in a wide variety of contexts ranging from suggestions from citizens and elected officials to real-time design and location decision making in public forums and meetings.

NCHRP PROJECT TO DEVELOP CONCEPT FOR EIM&DSS

In recognition of the specific needs of transportation agencies that exceed those of an ISO 14001 EMS, the state DOTs through AASHTO's NCHRP initiated NCHRP Project 25-23, "Environmental Information Management and Decision Support System for Transportation."

The ultimate objective of the project was to develop a concept for an EIM&DSS that addresses the following levels of decision making:

- **Planning—**Developing a vision for the future and laying out the steps, the resources required, and a schedule to realize the vision. Examples of plans include strategic, policy, long-range, system, modal, intermodal, corridor, and business plans.

- **Programming—**Developing a priority list of projects and other activities that can be accomplished within limited funds or other constraints. Examples of programs are state and regional transportation improvement programs (TIPs) and specific areas to receive funding such as wetland protection, bridge maintenance, or dredging of ports.
- **Project Development—**Designing, building, and implementing a specific project. Projects include constructing a new airport, building a traffic management center, and reconstructing a highway.
- **Operations—**Controlling the movement of goods and people on a specific facility or transportation system. Controlling ramp meters on freeways, coordinating traffic signals, and running trains, buses, and demand-responsive paratransit are all examples of operations. Snow and ice control and emergency responses are also considered operations.
- **Maintenance—**Undertaking actions to preserve and extend the life of existing transportation assets. Typical maintenance activities include joint and crack sealing of highways, preventive maintenance of rolling stock, and painting bridges. Mowing, cleaning drainage structures, and activities focused on signs, pavement striping and markers usually fall within the maintenance program.

The main product of this NCHRP Project is this handbook, which does the following:

1. Defines a concept for an EIM&DSS that satisfies the requirements of a broad range of transportation agencies for environmental information management and decision support,
2. Provides alternative implementation strategies, and
3. Provides a self-assessment tool to allow an agency to select the implementation strategy that best fits its needs.

DEFINITION OF EIM&DSS

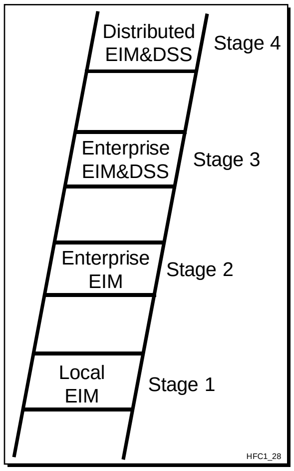
The definition of an EIM&DSS used in this handbook is more specific to transportation decision making and environmental information needs than the ISO 14001 standard:

> *…any system that strives to provide decision makers involved in planning, programming, project development, operations, and maintenance for any mode of transportation with the right information and analysis, in the right format, and at the right time to make specific decisions and to continually improve the outcomes of the agency's activities, operations, products, and services when measured in terms of transportation, environmental, social, cultural, and economic factors.*

This definition is intended to encompass the performance-based planning and continuous quality improvement framework of the ISO 14001 standard, and thus an EIM&DSS would be compliant with it.

PRACTICAL IMPLEMENTATION STRATEGIES

The concept for the EIM&DSS places a premium on practical implementation strategies that keep abreast of technological change. This handbook defines several implementation phases (see figure in sidebar) and provides a self-assessment tool for determining what stage of evolution an agency has achieved and what is the most practical implementation phase to pursue. The four implementation stages are as follows:



- **Stage 1. Local Project-Level Environmental Information Management System—**This system would consist of a database and GIS on a desktop computer or server on a local area network (LAN) that can provide a wide variety of environmental, social, cultural, and economic information primarily aimed at project-level decision making, compliance with environmental laws and regulations, and meeting needs for public involvement.

- **Stage 2. Centralized Enterprise Environmental Information Management System for all levels of decision making—**Analysts, managers, and decision makers from throughout the agency would be able to access environmental, social, cultural, and economic data and information stored in a central database/GIS/CADD system that can be used as input for all levels of decision making. However, information and analysis would not necessarily be provided in the right format at the right time for an intended audience in order to support decision making. Although information and analysis would exist for project alternatives, there would be limited ability to conduct alternative analysis or assess various scenarios regarding plans, programs, operations, and maintenance.

- **Stage 3. Centralized Enterprise EIM&DSS for all Levels of Decision Making and All Modes—**Analysts, managers, and decision makers throughout the agency would be able to obtain information and analysis regarding various options or alternative scenarios regarding planning, programming, project development, maintenance, and operations. Information in the database would be static and would be the product of previously completed data entry and analysis. Interfaces would exist between the EIM&DSS database and other key management and decision support systems to facilitate the transfer of data and analysis from these systems to the EIM&DSS database. The EIM&DSS would use information and systems that are generally internal to the agency. Decision support output from the EIM&DSS would be expressed in terms of quantitative measures of value added, outcomes, outputs, and resources as well as non-quantitative information. The EIM&DSS would support a wide variety of presentation formats ranging from slides to GIS maps to digital imagery.
- **Stage 4. Distributed EIM&DSS for All Levels of Decision Making and all Modes—**This stage represents the ultimate vision for the EIM&DSS and anticipates the technological evolution toward pervasive distributed computing and access over the Internet to information and applications both within and outside an organization. Analysts, managers, and decision makers would be able to obtain information and analysis in the right format at the right time for the intended audience virtually on the fly. Users could use desktop computers, handheld computers, or other devices to obtain data and information stored inside or outside the agency, exercise management systems (e.g., pavement, bridge, congestion, intermodal, safety, maintenance, construction, and equipment) and simulation models (e.g., air, water, noise, land use, and species diversity) in order to quickly analyze alternatives addressed at each level of decision making: planning, programming, project development, operations, and maintenance. Decision inputs would be expressed in terms of quantitative measures of value added, outcomes, outputs, and resources as well as non-quantitative information. The EIM&DSS would support a wide variety of presentation formats ranging from slides to GIS maps to digital imagery to virtual reality.

All stages of development would involve access to information on environmental best management practices (BMPs) and have content and workflow management systems. Content management systems are used to manage data and information over its life cycle and include metadata—data about the data in the EIM&DSS. Workflow management systems allow for the transfer of information and analysis according to prescribed business processes that would be specified in business process flow diagrams.

BENEFITS OF AN EIM&DSS

The benefits of an EIM&DSS are manifold and include the following:

- An EIM&DSS greatly enhances the ability of a transportation agency to be an effective steward of the environment while carrying out its mission.
- An EIM&DSS provides relevant, useful, well-formatted, accurate, and timely information and analysis for all levels of decision making—planning, programming, project development, operations, and maintenance.
- An EIM&DSS supports the transportation and environmental business processes of a transportation agency.
- An EIM&DSS supports the wide variety of ways different users might interact with and use such a system.
- An EIM&DSS provides a performance-based planning framework that relies on measurement of environmental outcomes to continuously improve environmental management and performance.
- An EIM&DSS facilitates communication regarding environmental issues, facts, and analysis with various members of the public, including citizens, elected officials, and special interest groups.
- By encouraging early consideration of issues in the planning and programming phase, an EIM&DSS helps streamline the business process and minimize the likelihood of project delays and aborted projects.

HOW TO USE THE HANDBOOK

This handbook is a practical guide for implementing an EIM&DSS. Agencies can implement the EIM&DSS on their own, as a part of a pooled-fund effort of transportation agencies, or in partnership with the private sector.

The handbook is organized to take agencies step by step through an implementation process that helps the agency to achieve full commitment and buy-in and gather the resources over time in order to achieve the agency's short-, mid-, and long-run implementation goals.

This handbook provides procedures that take into account the unique characteristics of an agency, including an agency's current stage of evolution, the technical environment in which the agency operates, and the agency's plans to accommodate technological change.

The most important things to keep in mind while using the handbook are as follows:

- Pay particular attention to the key issues in getting started and achieving buy-in. These key issues include enlisting a champion, obtaining funding, establishing a task force, and deciding whether the agency will develop the EIM&DSS on its own or in partnership with others.
- Develop a clear understanding of the ultimate concept for the EIM&DSS. There are many different views of the system offered in this handbook and each provides a perspective important to understand.
- Use the self-assessment tools to identify how far the agency has evolved toward the ultimate concept, identify a path to develop and implement the desired concept, and set short-term and intermediate implementation goals.
- Develop the EIM&DSS in affordable and manageable increments and use a phased approach to implementing the whole concept. Seek to understand those parts of the system the agency will be implementing in a particular phase and those parts the agency will defer to future phases.
- Carefully follow the guidance on system design, development, implementation, operations, and maintenance, including use of best practices for life cycle management of systems and software.
- Remember that content management is crucial to system success and that data and information must be properly managed over its lifecycle. Make sure that the benefits of having a particular type of data exceed the life cycle costs of the data.
- Pay attention to the icons throughout the handbook that offer tips, cautions, ideas, and other guidance for successful implementation of the EIM&DSS.

ORGANIZATION OF THE HANDBOOK

The remaining part of the handbook is organized as a series of implementation steps. By following them, an agency will develop a clear understanding of what the requirements are and the vision of the EIM&DSS based on the research conducted under NCHRP Project 25-23. Agency staff will assess existing capabilities, which will enable staff to see the gap between the agency’s current capabilities and the vision for the EIM&DSS. Staff will assess alternative migration paths from the agency’s current stage of development to the fully realized concept for the EIM&DSS and take into account the evolution of technology. Next, staff will develop a phased implementation plan. Finally, each phase that the agency implements should be in accord with a sound lifecycle methodology for software development.

Figure 5 provides an overview of the EIM&DSS implementation steps that are explained in detail in the remainder of this handbook.

Figure 5. Implementation Steps

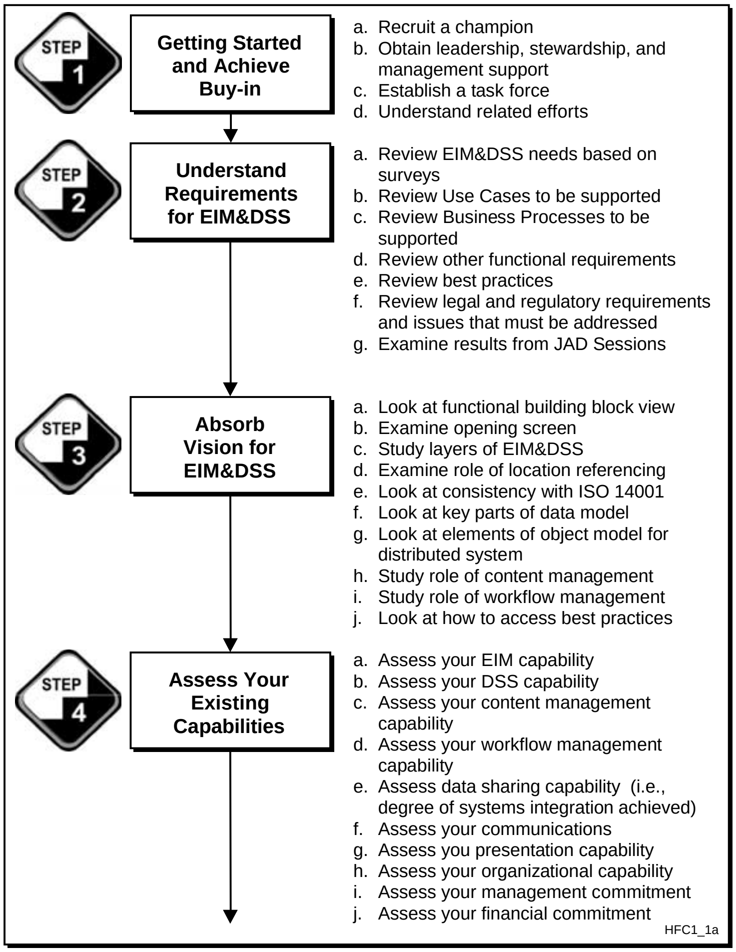
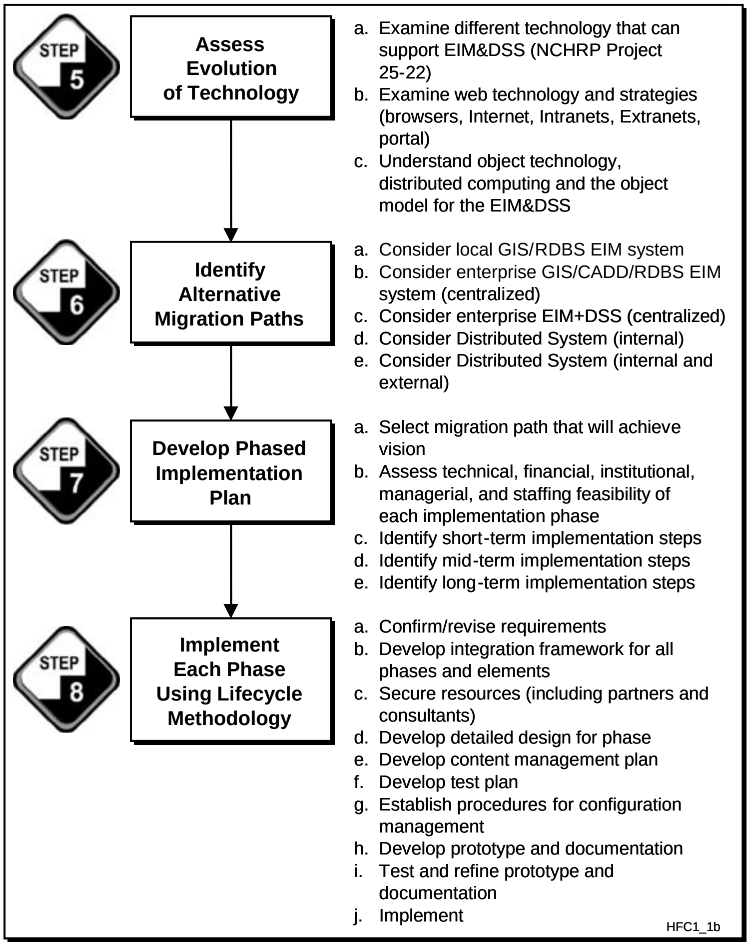


Figure 5 (Continued). Implementation Steps



a. Examine different technology that can support EIM&DSS (NCHRP Project 25-22)
b. Examine web technology and strategies (browsers, Internet, Intranets, Extranets, portal)
c. Understand object technology, distributed computing and the object model for the EIM&DSS

a. Consider local GIS/RDBS EIM system
b. Consider enterprise GIS/CADD/RDBS EIM system (centralized)
c. Consider enterprise EIM+DSS (centralized)
d. Consider Distributed System (internal)
e. Consider Distributed System (internal and external)

a. Select migration path that will achieve vision
b. Assess technical, financial, institutional, managerial, and staffing feasibility of each implementation phase
c. Identify short-term implementation steps
d. Identify mid-term implementation steps
e. Identify long-term implementation steps

a. Confirm/revise requirements
b. Develop integration framework for all phases and elements
c. Secure resources (including partners and consultants)
d. Develop detailed design for phase
e. Develop content management plan
f. Develop test plan
g. Establish procedures for configuration management
h. Develop prototype and documentation
i. Test and refine prototype and documentation
j. Implement

Readers are urged to follow the recommended steps carefully. A substantial amount of software will need to be developed, many systems and models need to be integrated, and data collection must be carefully orchestrated so it matches each incremental step of development.

ICONS

This implementation handbook has icons in the margins in order to provide the reader guidance and call attention to key points. In some cases, the icons serve the purpose of cautioning the reader regarding specific problems or pointing out an approach that may be helpful. The following icons are used in this handbook.

Exercise caution:

A good idea:

Here is a tip:

A numbered step:

A rigorous approach:

STEP 1. GET STARTED AND ACHIEVE BUY-IN

INTRODUCTION

Perhaps the agency is already convinced that there are compelling reasons to have an EIM&DSS. However, agency staff may have only a vague concept of what the agency is trying to implement and the challenges ahead. How should the agency get started? How can the agency begin to obtain a sharper vision? How should the agency reach a consensus regarding the requirements of the system? How can agency staff convince others that the system will support their business processes and provide the needed information and timely decision inputs in a user-friendly manner?

The answers to these questions can be found by (1) taking meaningful steps to get started such as by establishing leadership for the effort; (2) developing an understanding of system requirements, and (3) trying to absorb the vision for the EIM&DSS. These initial three steps are not linear; agency staff will want to strengthen certain starting activities such as achieving buy-in from top management as staff gain a deeper understanding of system requirements and the vision for the system. Indeed, staff may need to work through some of the later steps of the implementation process before they fully understand what they wish to accomplish.

RECRUIT A CHAMPION

The first thing to do in developing an EIM&DSS is to identify a champion for the effort. Probably at least one person in the agency has begun to champion the idea. The champion is often the spark plug that gets a project started and this person often has more influence on the project’s success than anyone else. The champion grasps the potential value of the undertaking, is excited about pursuing it, can act and solve problems, and can build enthusiasm and support within the organization to develop and implement the EIM&DSS.

It is also wise to identify another person who is enthusiastic and committed and can serve as a backup champion. Many projects languish or fail because a champion gets promoted or leaves an organization for a better job and no one is available to take that person’s place.

OBTAIN LEADERSHIP, STEWARDSHIP, AND MANAGEMENT SUPPORT

Developing and implementing an EIM&DSS is a complex undertaking that requires leadership. Leaders need to be able to articulate the vision for the EIM&DSS and enlist others to realize the vision. Leadership is also required to marshal the necessary financial, staff, and technical resources in a timely manner. In the case of environmental management, part of leadership is communicating the importance of environmental stewardship and the value of having information management and decision support tools for improving environmental quality.

ESTABLISH A TASK FORCE

The agency will need a task force, steering committee, or similar group that includes representation of important stakeholders and future system users. An important role of the task force will be to represent key parts of the agency to ensure there is proper input and feedback. The task force should report to top management. At a minimum, members should include key managers from the following:

- Environmental services unit or bureau;
- Selected key environmental areas (e.g., air, water, waste, wildlife, and habitat);
- Planning;
- Programming;
- Project design and delivery;
- Operations;
- Maintenance;
- Computer services, communications, and information technology; and
- Several modes of transportation (e.g., highway, transit, rail, air, and water).

It is also desirable to add members from outside the agency, such as regional and federal agencies, regulatory and environmental resource agencies, consultants, and contractors. The task force will direct and oversee progress toward the development and implementation of the EIM&DSS, including procurement activities. The task force will need to reach an agreement on the level of effort required to develop the

EIM&DSS and prepare a recommended approach, budget, schedule (including phasing and tasks), and implementation strategy. The implementation strategy, at a minimum, needs to address whether the organization will develop the EIM&DSS on its own or through some cooperative, cost-sharing arrangement with other organizations.

APPOINT A PROJECT MANAGER

The task force will need to appoint a project manager. The project manager may or may not be the champion. The project manager has many roles, including the following:

- Managing project staff and other resources;
- Keeping the project on schedule;
- Monitoring and mitigating risks;
- Ensuring the quality of all deliverables;
- Serving as the technical representative and first point of contact with contractors or consultants;
- Serving as the first point of contact with partners (e.g., states, MPOs, and private firms);
- Making day-to-day decisions that do not require task force or top management input; and
- Keeping the task force and top management abreast of progress, key issues, and problems that need resolving.

SEEK PARTNERS

Consider forming a partnership to develop and test the EIM&DSS. The advantages of a cooperative effort include reduced costs for each agency involved, and broader, more balanced guidance to the contractor developing the software. An agency can also involve private firms in the development effort, especially if the focus will be on information and file sharing with engineering firms performing design work for the agency.

UNDERSTAND RELATED EFFORTS

It is important to become fully informed about related efforts occurring within the agency. These include the development of a performance-based planning system that includes environmental performance measures, creation of an enterprise data management system, development of asset management systems that provide transportation analysis and decision support, and development of environmental models and procedures that could eventually be incorporated in an EIM&DSS. Also, be aware of GIS or integrated GIS/CADD systems that can serve as the foundation for an EIM&DSS.

OBTAIN TOP MANAGEMENT SUPPORT

TIP

Agency staff will need to obtain the support of top management to ensure the organization is willing to commit the resources necessary to develop the EIM&DSS.

Reading this entire handbook can help provide staff with perspective on what to convey to top management, especially with respect to the funding required. Staff will need to communicate what implementation steps they propose to take in the short, mid, and long run, as well as the benefits and costs associated with each phase.

OBTAIN CONSULTANT OR PEER GROUP ASSISTANCE

TIP

Consider adding consultant or peer group assistance to help develop the scope, approach, schedule, and budget when in-house expertise is not available.

Many issues, complexities, and challenges must be addressed in developing an implementation plan and working through the early steps, such as establishing the scope approach and budget for the EIM&DSS. Many agencies will not have the staff and the expertise to proceed on their own and may find such groups useful.

STEP 2. UNDERSTAND REQUIREMENTS FOR THE EIM&DSS

The next step in implementing an EIM&DSS is to establish requirements and develop an understanding of the elements of an EIM&DSS that represent the system modules or building blocks. A substantial effort was made under NCHRP Project 25-23 to establish requirements that would satisfy virtually any state DOT or MPO.

However, no agency is likely to try to satisfy all the requirements at once because of the cost, risk, and complexity. Instead, states and MPOs are more likely to pursue a staged approach of incremental development and implementation (see Steps 4 through 8).

Top-Down,Customer-Driven Approach and Key Functional Elements

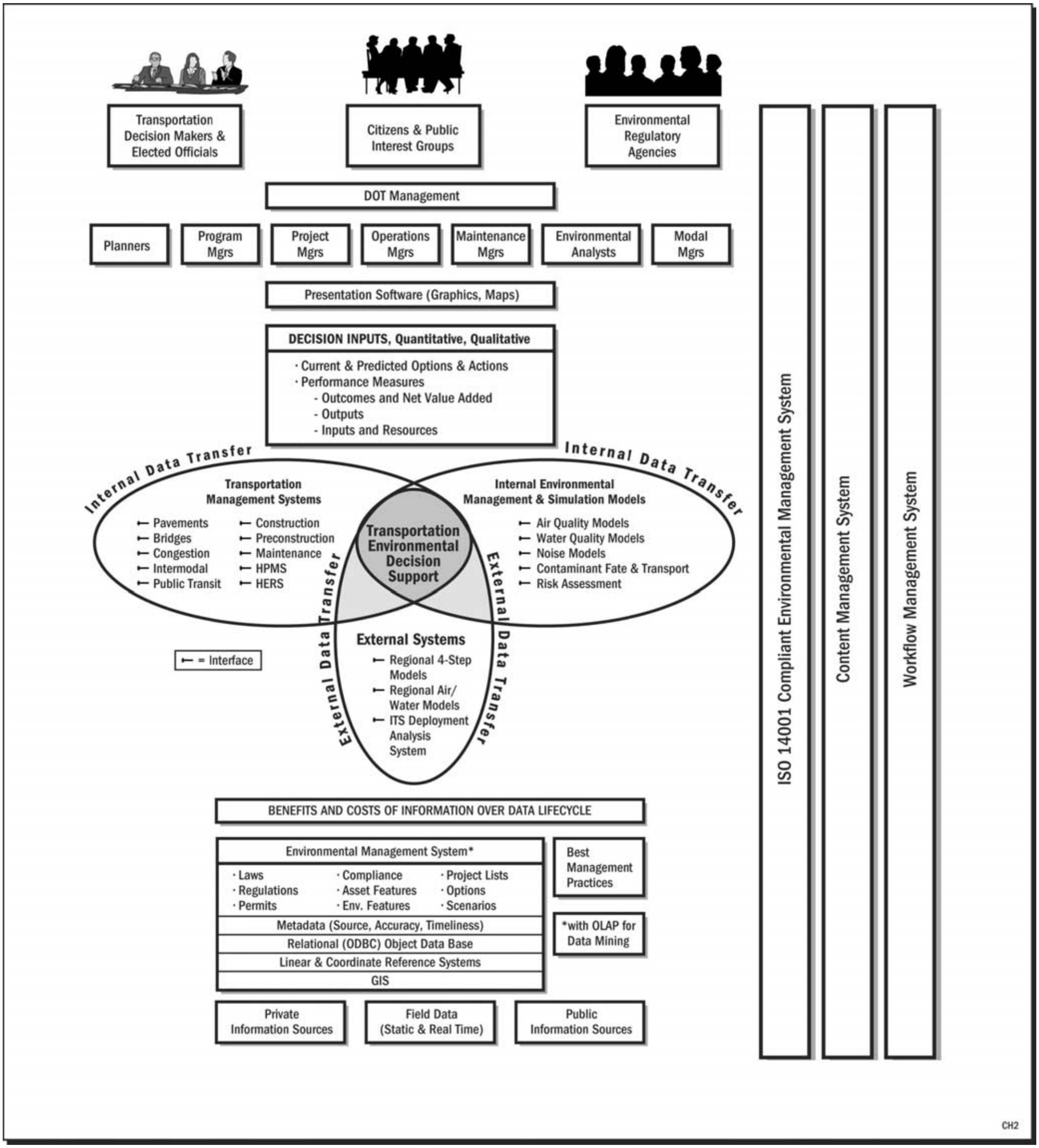
Requirements for the EIM&DSS were established by focusing on the kind of information that decision makers require in order to make decisions in a manner that is highly sensitive and responsive to key stakeholders and customers. In other words, requirements were established using a top-down, customer-driven approach as illustrated in Figure 6.

Figure 6 shows how the decision support needs of transportation decision makers, elected officials, citizens, public interest groups, and regulatory agencies first translate into presentation needs that ensure that the right information is delivered in the right format to a particular audience in a specific setting. Presentation formats include slides, poster boards, video, a visual drive-through of the design concept, and handouts discussing options and impacts.

Each decision—whether it occurs at the planning, programming, project development, operations, or maintenance level—requires a set of decision inputs for each alternative or scenario under consideration.

The quantitative decision inputs consist of direct, indirect, and cumulative transportation, environmental, social, cultural, and economic impacts. These impacts may be presented in terms of various types of performance measures: net value added, outcomes, outputs, and inputs. Qualitative information may consist of descriptive material or imagery.

Figure 6. Top-Down, Customer-Driven Approach To Establishing Requirements for EIM&DSS



The decision inputs define what type of analysis is required. Therefore, these decision inputs define (1) what types of results transportation and environmental management systems and models should produce and (2) any information that might come directly from a GIS and a CADD system.

Once the purposes of transportation and environmental management systems and models have been established, the data input requirements of these models and systems readily follow. These data inputs are stored in the EIM database.

The foundation of the system is the EIM system layer. In theory, no information should be put in the database comprising this layer unless the information has utility for decision making. One should be able to trace the need for the information back up through to the step shown at the top of Figure 6. If there is neither a direct need for the data as a decision input nor an indirect need for the data (because the data is an input to a model that produces output directly useful to decision makers), then the information does not belong in the database.

Data needs should be determined partly by the benefits and costs of the data with respect to how they affect the net value, outcomes, outputs, and inputs important to customers, stakeholders, and decision makers. Figure 6 illustrates the importance of assessing the benefits and costs of information over the data lifecycle.

Ultimately, the data comes from public and private information sources and may include field data that can be static or real time. Examples of real-time data are pollution concentrations on ozone alert days, progress in cleaning up oil spills, and traffic data being automatically collected and communicated to traffic operations centers and Internet sites.

APPROACHES TO ESTABLISHING REQUIREMENTS

The requirements for the EIM&DSS encapsulated in Figure 6 were refined using various methods that, when taken together, help provide a detailed picture of a concept for the EIM&DSS. As part of the first step toward implementing an EIM&DSS, the agency should review the following requirements:

- Information management and decision support needs based on surveys of state DOTs and MPOs;

- Use cases that need to be supported (Use cases are defined as ways that different users might interact with or use the system);
- Business processes that need to be supported;
- Functional requirements that are essential;
- Needs based on best practices for environmental information management and transportation decision support;
- Legal and regulatory requirements; and
- Additional needs established in JAD sessions with state DOTs and others.

REVIEW EIM&DSS NEEDS BASED ON SURVEY RESULTS

Survey Results

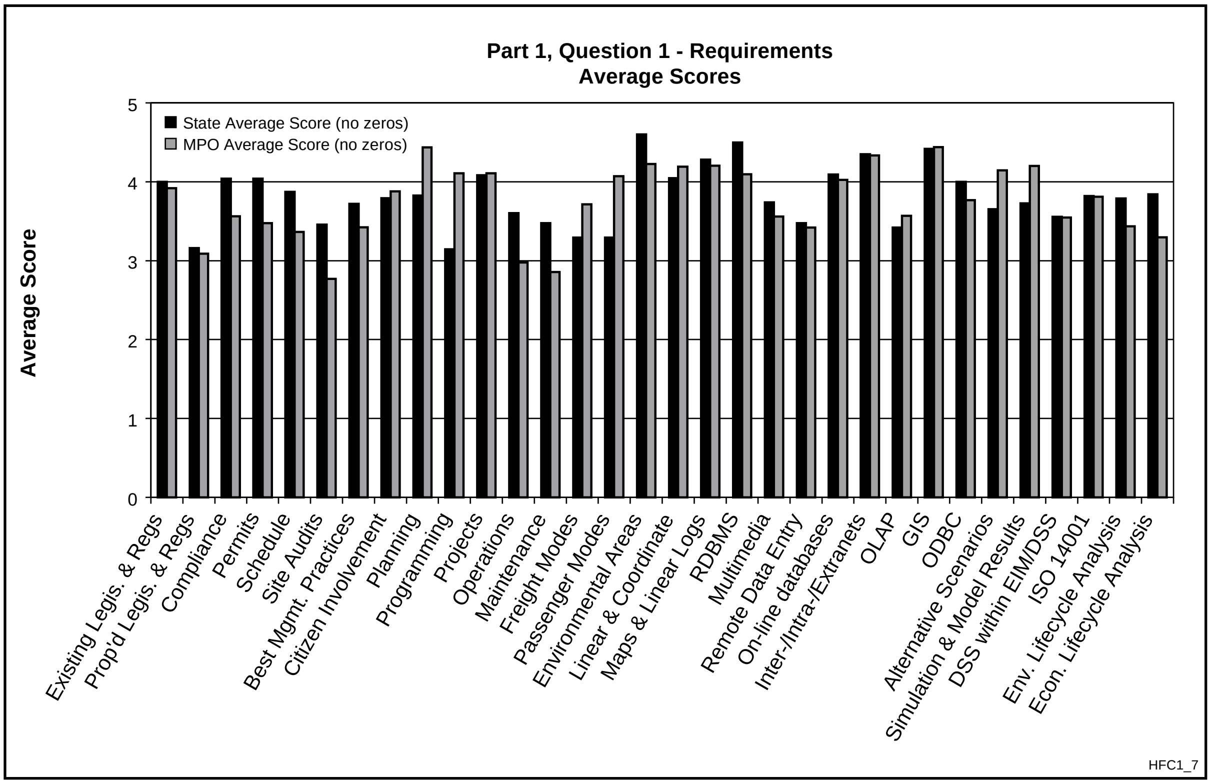
Valuable input regarding requirements for an EIM&DSS were obtained by distributing two surveys—one to all state DOTs and all Canadian provinces and the other to MPOs.

A total of 688 surveys were distributed to state, provinces, and MPOs, and 80 were returned. Copies of the two survey instruments and a tabulation of survey results appear in Appendix B. In the discussion below, responses from states, Canadian provinces, and transportation authorities are termed “States” and the rest are termed “MPOs.”

EIM&DSS Requirements

Both surveys asked respondents to rate, on a scale of 1 (unimportant) to 5 (important), how important it is for an EIM&DSS to have various characteristics (i.e., satisfy specific requirements). Figure 7 summarizes the average score of states and MPO respondents. As might be expected, the most important requirement of the EIM&DSS is that it address all environmental areas. Other important characteristics both states and MPOs identified were that the EIM&DSS have a GIS, a relational database, Internet/Intranet/Extranet telecommunications, linear and coordinate referencing systems, maps and linear logs, and project-level information and decision support. MPOs placed greater importance than states on an EIM&DSS that addresses planning and programming. Both states and MPOs placed relatively less importance on an EIM&DSS that addresses operations and maintenance. States indicated that information on environmental legislation and

Figure 7. Average State and MPO Response to EIM&DSS Requirements



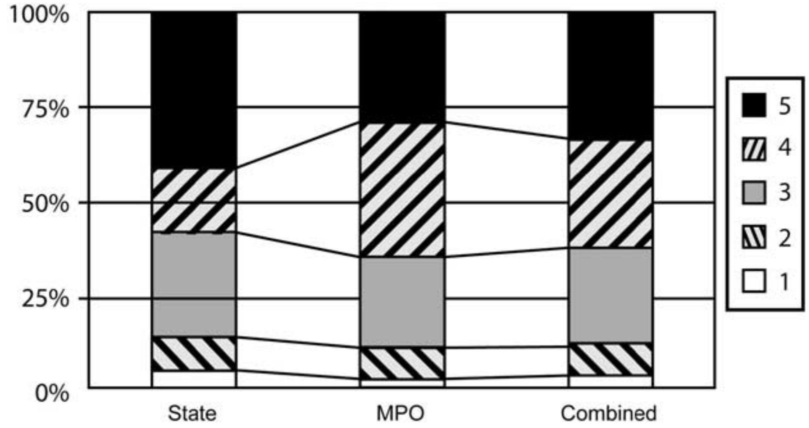
regulations, compliance, and permits was also important. It should be emphasized that all the characteristics were considered important by at least one state or MPO and that the average state rating for all characteristics or requirements equaled or exceeded "3." The average MPO score fell below "3" only for the needs to address maintenance and operations and to address site audits.

Nearly three-quarters of the MPOs and at least one-half of the states gave a "4" or "5" to the need to store alternative transportation and environmental simulation and decision support scenarios in the EIM&DSS. States and MPOs expressed a need similar to one another to store final and intermediate results from transportation simulation and decision support models and the ability to link environmental impact analysis models or impact matrices to those results.

M METHOD Rigorous

Well over one-half of the states and MPOs gave a rating of "4" or "5" to the need to satisfy the requirements for the ISO 14001 EMS. Only a very small percent indicated it was unimportant or not very important that the EIM&DSS satisfy this international standard (See Figure 8).

Figure 8. State and MPO Response to ISO 14001 Requirement



Current and Future Needs for Information and Decision Support

Respondents were asked to identify current and future needs for different types of environmental information and decision support. Table 3 summarizes the answers for all respondents. Overall, information needs were deemed more important than decision support needs. States tended to emphasize information needs while MPOs saw a less clear distinction between information and decision support needs. Current and future information and decision support needs are highest in the areas of air quality, land use, and environmental justice. Current information and decision support needs in the areas of accessibility, mobility, economic growth and wetlands are also relatively great. In the future, information and decision support needs regarding noise, hazardous wastes, wildlife, vegetation, parkland, community cohesion, aesthetics, urban design, and marine/fisheries are higher than current needs.

Decision Support Systems or Simulation Models

Respondents were asked to name different levels of decision making for which they use decision support systems and simulation models and to name the models. Overall, there was a relatively low response rate on this question. States tend to (1) use models for air quality and noise analysis and (2) emphasize planning and projects. MPOs tend to (1) use models for air quality and land use analysis and (2) emphasize planning.

Table 3. Combined State and MPO Response to Information and Decision Support Needs

Environmental, Social, and Economic Area	Current Environmental Assessment Needs		Future Environmental Assessment Needs	
	Information	Decision Support	Information	Decision Support
Air Quality	75%	71%	73%	68%
Water Quality	51%	38%	54%	44%
Noise	51%	40%	60%	53%
Hazardous Waste	45%	31%	50%	36%
Solid Waste	40%	26%	40%	28%
Wildlife	53%	34%	55%	44%
Vegetation	45%	25%	46%	36%
Wetland	61%	53%	59%	54%
Parkland	53%	34%	58%	41%
Environmental Justice	81%	65%	74%	63%
Community Cohesion	49%	33%	60%	44%
Aesthetics	43%	24%	45%	29%
Urban Design	55%	29%	56%	36%
Accessibility	70%	55%	64%	51%
Mobility	70%	56%	65%	54%
Economic Growth	74%	55%	70%	55%
Residential Relocation	55%	31%	50%	30%
Business Relocation	46%	26%	43%	28%
Land Use	80%	69%	76%	68%
Historic/Archeological	63%	48%	58%	43%
Marine/Fisheries	30%	18%	34%	23%
Stormwater/Drainage	59%	44%	54%	44%
Civil Rights	50%	29%	50%	29%
Abutter/Landowner	40%	18%	36%	21%

Geographic Information Systems (GIS)

Respondents were asked if they have a GIS and, if yes, the types of coverages they have and whether their database contains metadata. MPOs were also asked what they think are the metadata requirements of an EIM&DSS. **As expected, most states and MPOs said they have some form of a GIS and one-half of the MPOs indicated they have a metadata database as well (see Table 4). The types of metadata MPO respondents reported having and said was required included the sources of data, dates, quality of data, coverage, and contact information.** Appendix B, provided in *NCHRP Web Document 55,* includes a listing of their responses.

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Table 4. State and MPO Response to GIS/Metadata Implementation

	State	MPO	Combined
GIS	74%	92%	86%
Metadata*	NA	51%	NA

*Only asked on MPO survey

NA = Not available

Planning and Programming Processes

Some questions were asked in order to determine to what degree states and MPOs (1) assess environmental, social, and economic impacts of alternative plans and programs; (2) use planning and program-level analysis as input into subsequent levels of decision making; (3) conduct scoping meetings with outside regulatory agencies; (4) assess cumulative impacts; and (5) prepare environmental assessments or impact statements of plans and programs. Tables 5 through 9 present the responses of states and MPOs regarding environmental analysis activities for planning and programming.

Table 5. Combined State and MPO Response to Planning Processes

Type of Planning	Do you define alternative plans and assess their environmental, social, and economic impacts?	Do you use planning analysis results as input into subsequent levels of decision making?	Do you conduct scoping meetings with outside regulatory agencies?	Do you assess the cumulative effects of different types of social, economic, and environmental impacts?	Do you prepare an environmental assessment or impact statement?
Long-Range Planning	59%	65%	34%	36%	13%
System Planning	36%	44%	18%	19%	4%
Policy Planning	24%	33%	14%	15%	4%
Strategic Planning	26%	28%	13%	14%	8%
Corridor Planning	69%	64%	43%	35%	31%
Intermodal Plan	28%	36%	16%	14%	9%
State/Regional Highway Plan	41%	51%	25%	25%	16%
State/Regional Rail Plan	19%	25%	20%	14%	8%
State/Regional Airport Plan	23%	29%	19%	16%	10%
State/Regional Waterways/Port Plan	10%	16%	10%	5%	5%
State/Regional Transit Plan	35%	44%	23%	23%	11%
State/Regional Intercity Rail Passenger Plan	10%	19%	13%	13%	6%
State/Regional Bike Plan	29%	36%	16%	16%	6%
State/Regional Recreational Trails Plan	15%	18%	8%	8%	4%
Planning Elements TCM/TSM	34%	36%	19%	16%	6%

Table 6. State Response to Programming Needs

STATE (Part 3, Question 1)

Type of Programming	Do you define alternative programs and assess their environmental, social, and economic impacts?	Do you use programming analysis results as input into subsequent levels of decision making?	Do you conduct scoping meetings with outside regulatory agencies?	Do you assess the cumulative effects of different types of social, economic, and environmental impacts?	Do you prepare an environmental assessment or impact statement?
State Transportation Improvement Program (STIP)*	33%	74%	41%	33%	19%
Metropolitan Transportation Improvement Program (TIP)	33%	59%	30%	37%	11%
Model Programs	26%	44%	19%	19%	15%
Other Specific Programs	7%	15%	11%	4%	0%

*Only asked on State survey

Table 7. MPO Response to Programming Needs

MPO (Part 2, Question 2)

Type of Programming	Do you define alternative programs and assess their environmental, social, and economic impacts?	Do you use programming analysis results as input into subsequent levels of decision making?	Do you conduct scoping meetings with outside regulatory agencies?	Do you assess the cumulative effects of different types of social, economic, and environmental impacts?	Do you prepare an environmental assessment or impact statement?
Metropolitan Transportation Improvement Program (TIP)	30%	34%	28%	17%	6%
Model Programs	19%	21%	15%	13%	9%
Other Specific Programs	2%	2%	4%	0%	0%

Table 8. Combined State and MPO Response to Planning and Programming Models

Model	Do you use for planning or programming	In the planning or programming process, do you use environmental analysis outputs from the model/system or use the model/system outputs as input into environmental simulation models?
Standard 4-Step	79%	38%
Traffic Simulation Models	39%	16%
ITS Deployment Analysis System	20%	6%
Highway Performance Monitoring System	36%	10%
Highway Economic Requirements System	4%	0%
Pavement Management System	34%	2%
Bridge Management System	26%	2%
Intermodal Management System	13%	2%
Public Transit Management System	16%	1%
Congestion Management System	42%	7%
Maintenance Management System	NA	NA

NA = Not available

Table 9. State and MPO Response on Whether Organization Holds Public Hearings/Meetings on Plans and Programs

Hearings/Meetings	State	MPO	Combined
Planning*	44%	NA	NA
Programming Hearings*	33%	NA	NA
Total Hearings (Average)	39%	72%	61%

*Distinction drawn only on State Survey

The only types of plans for which most states and MPOs define alternatives and assess impacts are long-range plans and corridor plans. States are more likely to define and analyze alternatives for corridor plans (85% versus 60%), but MPOs are more likely to define and analyze alternatives for long-range plans (66% versus 44%). Roughly one-half of both states and MPOs carry analysis results of these and state or regional highway plans into subsequent levels of decision making. Forty-three percent of states and MPOs combined conduct scoping meetings with outside regulatory agencies regarding corridor plans and 34% do so for long-range plans. Roughly one-third of states and MPOs combined assess the cumulative effects of their long-range and corridor plans. Nearly one-third of the states and MPOs prepare an environmental impact statement regarding corridor plans, but only

M METHOD Rigorous

a small fraction do so for other types of plans. However, environmental assessments or impact statements are prepared for all types of plans. Assessments of the cumulative effects of different types of environmental, social, and economic impacts also occur for all types of plans.

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Roughly one-third of the states and MPOs say they define alternative programs and assess their environmental, social, and economic impacts. Probably most states and MPOs that do this type of programmatic analysis are performing air quality conformity analysis. A high percentage of states say they use program analysis results as inputs into subsequent levels of decision making. States are more likely than MPOs to conduct scoping meetings, assess cumulative impacts, and prepare an environmental assessment or impact statement regarding programs.

States and MPOs were also asked which types of models, management systems, and decision support tools they use to support the planning or programming process. Seventy-nine percent of the combined respondents said they use the standard 4-step transportation modeling process, and somewhat more than one-third said they use traffic simulation models, the highway performance monitoring system, a pavement management system, and a congestion management system. More than 90% of the MPOs use the standard 4-step modeling process and more than 60% of the states use pavement and bridge management systems.

Project Development

Organizational units within states and transportation authorities responsible for project development were asked to identify environmental, social, and economic areas where they have or anticipate needs for information and decision support. The results were similar to those presented earlier in Table 3 and emphasize the importance of the EIM&DSS addressing all impact areas. These respondents placed more emphasis on project-level information and decision support needs for air quality, hazardous waste, and land use rather than community cohesion, aesthetics, and urban design. Economic areas such as economic growth and residential and business relocation were less heavily emphasized, but still were identified by 40% of the respondents.

Operations

States and MPOs were asked to indicate current and future environmental assessment needs for three areas of operations:

incident management, Intelligent Transportation Systems (ITS), and traffic signal control. The results appear in Table 10. The need for environmental analysis for operations, particularly regarding ITS, is expected to grow in the future.

Table 10. Combined State and MPO Response to Operations Needs

Environmental, Social, and Economic Area	Current Environmental Assessment Needs		Future Environmental Assessment Needs	
	Information	Decision Support	Information	Decision Support
Incident Management	43%	30%	38%	34%
Intelligent Transportation Systems	53%	43%	59%	50%
Traffic Signal Control	35%	28%	34%	26%

Maintenance

States have much greater need for environmental analysis related to maintenance than do MPOs both at present and in the future. More than one-half of the states see current information needs and future information and decision support needs regarding snow and ice control. Growing decision support needs are expected in most areas of maintenance (see Table 11). Interestingly, a higher percentage of MPOs (about 54%) identified current and future environmental information and decision support needs regarding ITS equipment maintenance in comparison with states (closer to 30%).

Table 11. Combined State Response to Maintenance Needs

Environmental, Social, and Economic Area	Current Environmental Assessment Needs		Future Environmental Assessment Needs	
	Information	Decision Support	Information	Decision Support
Pavement Maintenance	22%	30%	22%	37%
Shoulder Maintenance	37%	44%	37%	52%
Bridge Maintenance	44%	44%	37%	48%
Landscaping	48%	33%	44%	37%
Other Vegetation Management	48%	44%	44%	52%
Signs, Striping, and Markings	33%	33%	30%	30%
Drainage	44%	41%	37%	44%
Ice and Snow Control	56%	48%	52%	59%
Rest Area Maintenance	26%	26%	22%	30%
Signal Maintenance	19%	11%	15%	7%
ITS Equipment Maintenance	30%	15%	26%	11%
Safety Feature Maintenance	22%	19%	22%	19%

REVIEW USE CASES TO BE SUPPORTED

A fundamental requirement of the EIM&DSS is that it must serve all the important users of the system in each way they use or interact with the system. Each of these different ways of interacting with the system is called a "use case." More than 150 use cases were identified and classified into six categories as shown in Table 12. Use cases play an important role in systems development. One can set priorities for software development by focusing on use cases that, if supported, would provide the greatest net value added. Use cases are essential for

Table 12. Summary of Use Cases

Use Case Category	Use Case Descriptions	User
General	64	Chief Administrative Officer Deputy Commissioners Assistant Chief Administrative Officer (e.g., Assistant Secretary) Elected Official Public Interest Group/Industry Association Citizen State Engineer District Director Head, Pavement Management State Bridge Engineer Materials Research Engineer Head of Modal Bureau (e.g., rail, air, transit, ports, and waterways) Chief of Environmental Management Office Outside Environmental Agency Official (U.S. EPA, state environmental agency) Environmental, Social, or Economic Analyst (in house) Environmental, Social, or Economic Analyst (consultant)
Planning	23	Planning Director, Executive Director of MPO Environmental Planner General Planner Modal Planner Intermodal Planner Chief of Right-of-Way
Programming	9	Director of Budget and Finance Manager of Program Development Program Managers
Project Development	13	Planning Engineer Design Engineer Consultant Designer Project Engineer Project Inspectors
Operations	9	Chief of Operations Traffic/Systems Engineer Traffic Operations Center Manager
Maintenance	35	State Maintenance Engineer District Maintenance Engineer County Engineer Area/Garage Maintenance Engineer Superintendent Crew Leader Shop Manager Mechanic Snow Plow/Spreader Operator Maintenance Contractor—Chief Engineer Maintenance Contractor—Crew Leader

developing detailed computer interface design (especially procedures for navigating from screen to screen). Use cases are also invaluable for testing software to ensure that the software will accommodate the way a particular user expects to interact with the system.

Appendix C, provided in *NCHRP Web Document 55,* contains a complete description of all the use cases identified.

REVIEW BUSINESS PROCESSES TO BE SUPPORTED

Requirements for the EIM&DSS are partly encapsulated in business processes that are an integral part of environmental management. High-level business process requirements that must be supported by an EIM&DSS are as follows:

- Public performance reporting (ISO 14001, etc.),
- Public involvement,
- Planning,
- Programming,
- Project planning,
- Project design,
- Project construction,
- Mitigation/enhancement,
- Operation,
- Maintenance,
- Closure and decommissioning,
- Regulatory/policy compliance,
- Site audit,
- Exercise of simulations, models, and management systems,
- Program/project evaluation,
- Reporting/data mining,
- Remote data entry,
- Data sharing,
- Interface with external systems, and
- Overlap across business practices.

These requirements are the result of a synthesis of the literature review, team knowledge, survey input, and best practices documents submitted by states and MPOs.

Figures 9 through 18 are business process flow diagrams that represent additional procedures that an EIM&DSS needs to support. These procedures include the following:

Figure 9. Project Lifecycle

Sample Project Lifecycle Business Process

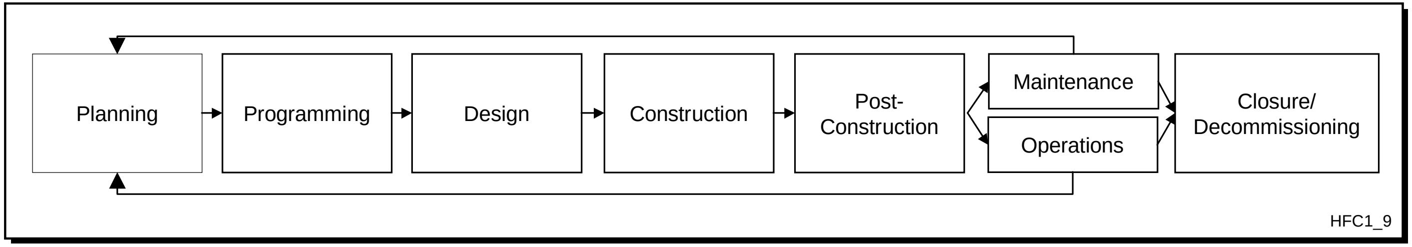
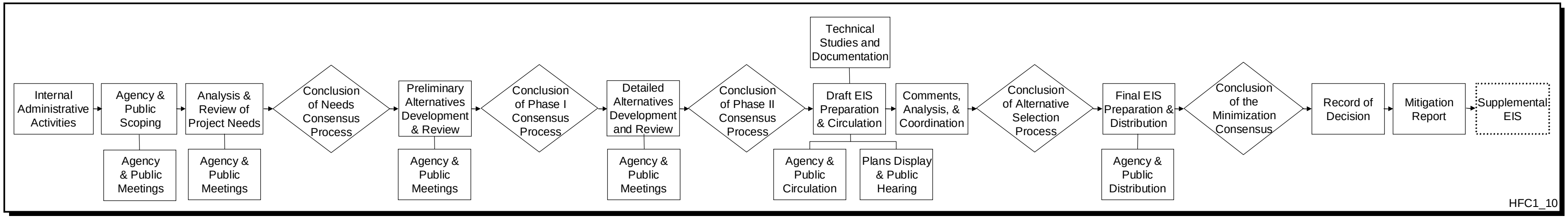


Figure 10. NEPA

Sample Project Development Business Process



Source: State of Pennsylvania Department of Transportation (1993 Edition, 1998 Printing: Change #1 included). *The Transportation Project Development Process - Environmental Impact Statement Handbook*.

Figure 11. Typical Program Development Associated with Grants-in-Aid

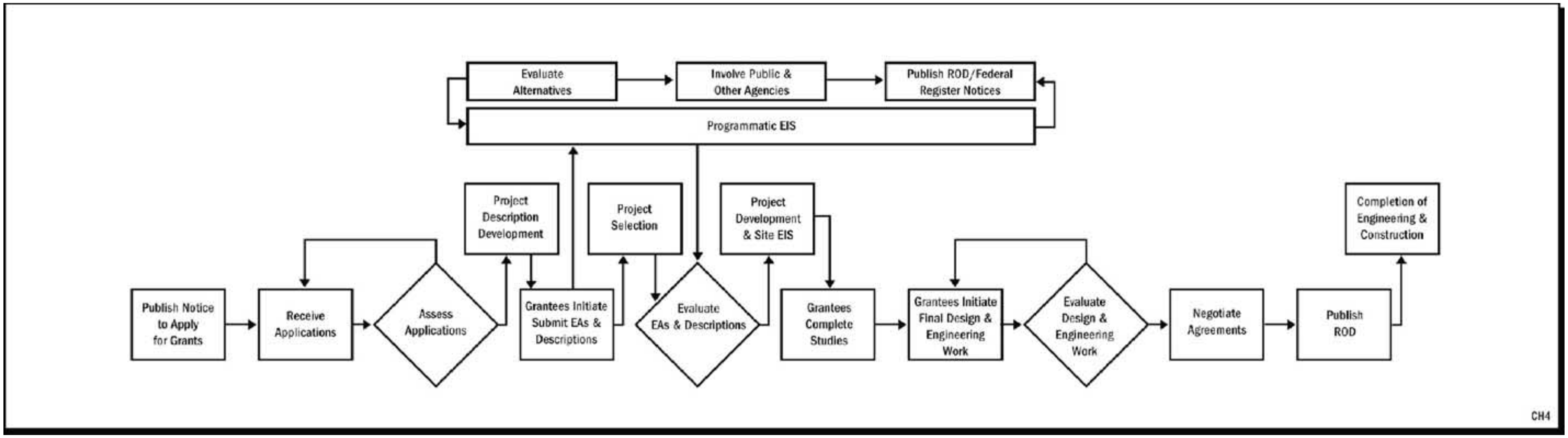
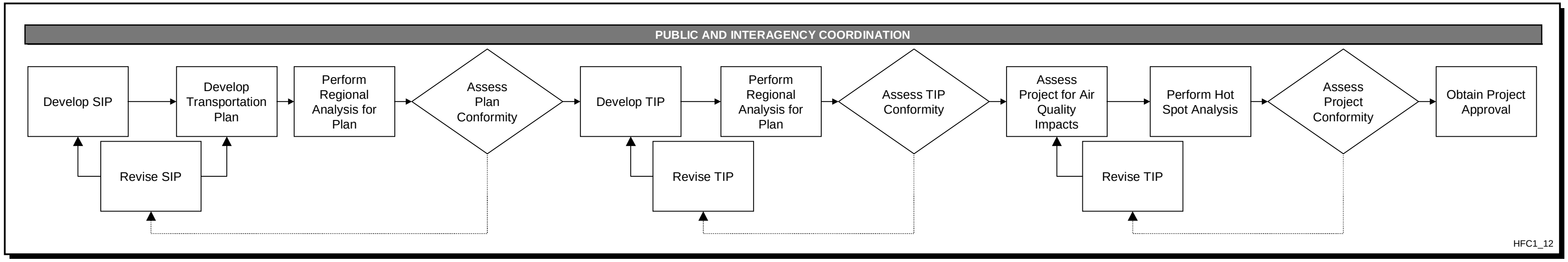


Figure 12. Air Quality Conformity

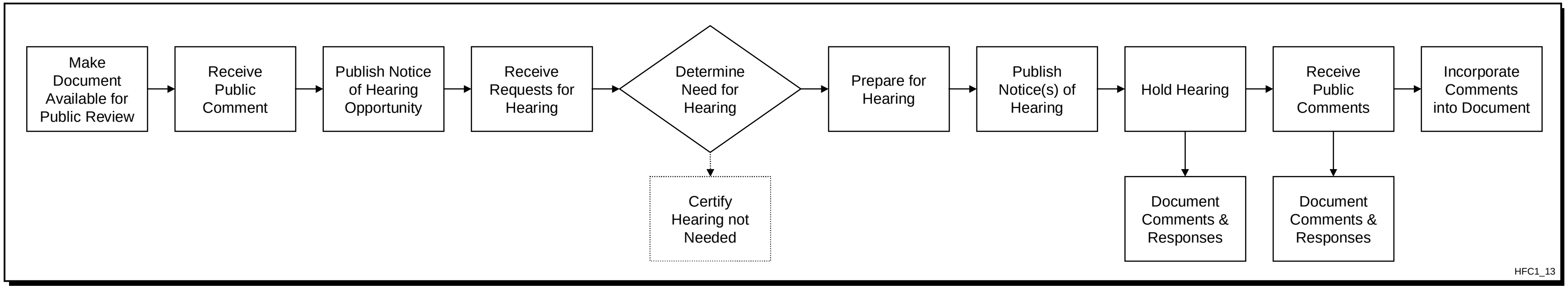
Sample Planning Business Process



Source: U.S. Department of Transportation, *Transportation Conformity: A Basic Guide for State and Local Officials*. (http://www.fhwa.dot.gov/environment/conformity/basic2gd.htm#whatis)

Figure 13. Public Involvement—Hearing/Meeting

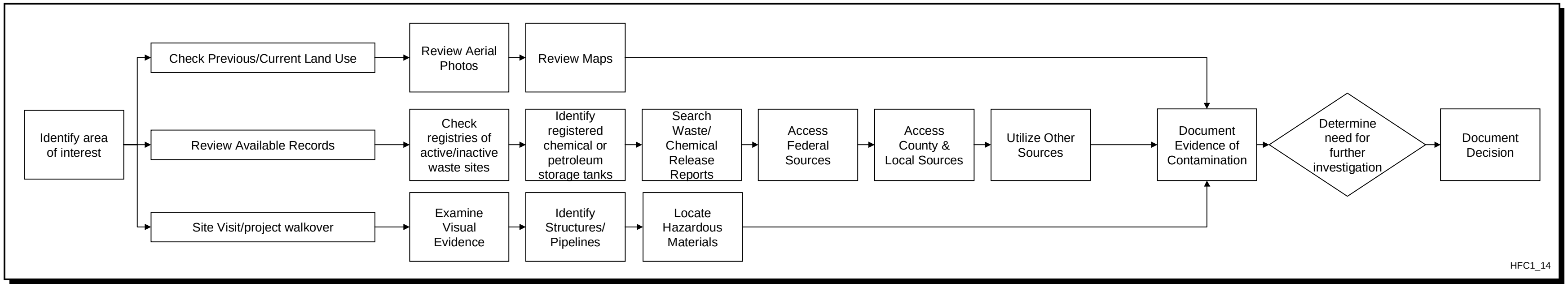
Sample Public Involvement Business Process



Source: State of Pennsylvania Department of Transportation (1995). *The Transportation Project Development Process—Public Involvement Handbook*.

Figure 14. Preliminary Site Assessment

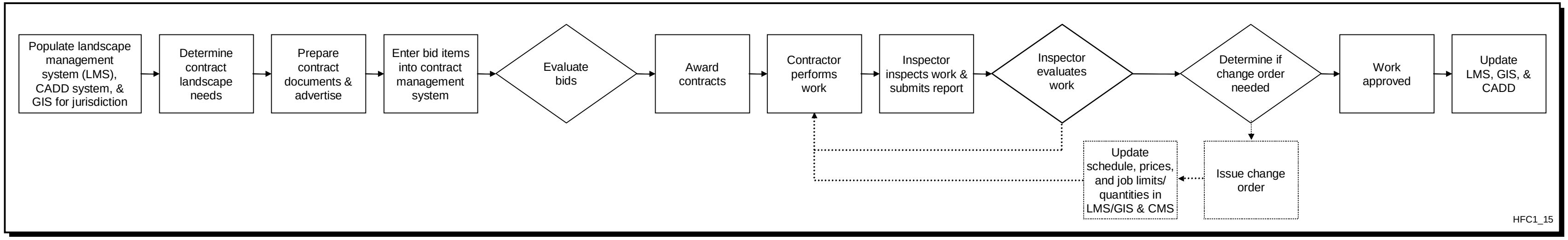
Sample Mitigation Business Process



Source: New York State Department of Transportation (1999). *NYSDOT Environmental Procedures Manual*.

Figure 15. Maintenance Landscaping

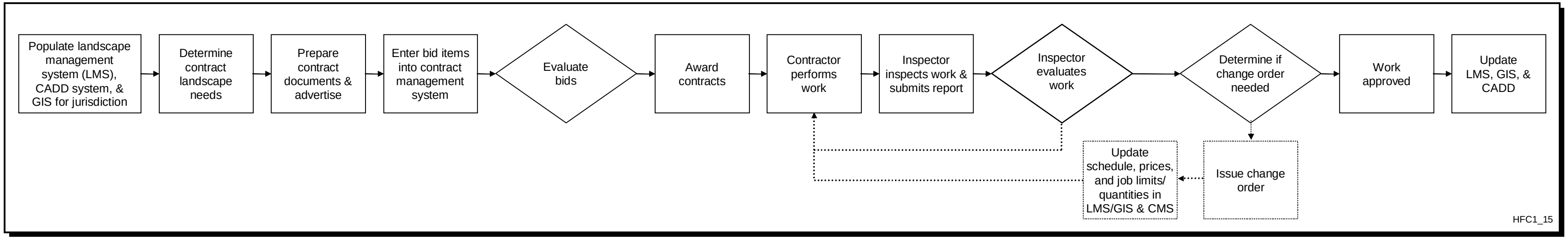
Sample Maintenance Business Process



Source: State of Maryland Department of Transportation State Highway Administration (February 2000). *System Functional Requirements, Volume 1.*

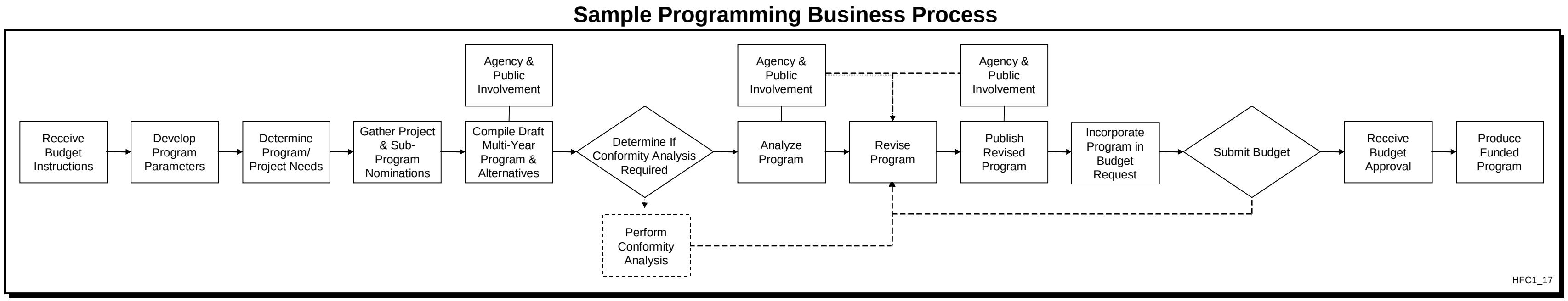
Figure 16. Snow and Ice Removal

Sample Maintenance Business Process



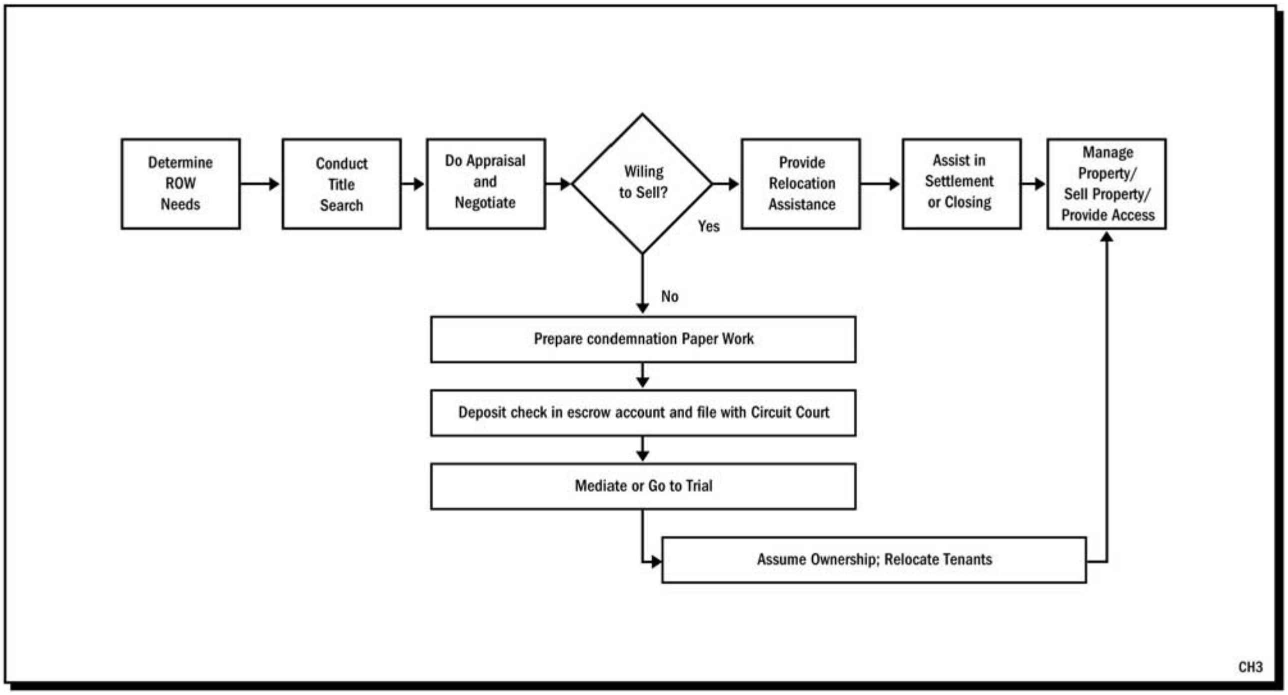
Source: State of Maryland Department of Transportation State Highway Administration (February 2000). *System Functional Requirements, Volume 1.*

Figure 17. State STIP Program Development Process



Source: Partly based on State of Wisconsin Department of Transportation (1979). *Six Year Highway Improvement Program - 1980-1985 - Summary.*

Figure 18. Rights-of-Way Management



- A typical project lifecycle business process,
- The NEPA process for a representative highway project,
- Typical program development associated with Grants-In-Aid,
- The air quality conformity process associated with development of a regional plan,
- A public hearing/meeting business process,
- A business process for conducting a preliminary site assessment regarding hazardous wastes,
- A business process for maintenance landscaping,
- Snow and ice removal,
- State TIP (STIP) development, and
- A business process for rights-of-way management.

DATA REQUIREMENTS

An EIM&DSS must support numerous high-level data requirements. For example, an EIM&DSS must access and/or manage the following:

- Documents,
- Alternatives and scenarios,
- Comments from the public and other agencies,
- Simulation and model results, and
- Plan sheets.

An EIM&DSS also must access and/or manage data relating to the following:

- Cost and schedule,
- Linear referencing,
- Coordinate referencing,
- Address matching,
- Impacts,
- Permits and compliance,
- Water issues,
- Air issues,
- Culture/history,
- Wildlife,
- Habitat,
- Land use,
- Noise,
- Mitigation,
- Waste/disposal,
- Socioeconomics,
- Traffic,
- Engineering, and
- Best management practices.

An EIM&DSS also must store and/or retrieve formats for the following:

- Geo-coded data,
- Spreadsheet data,
- Relational database data,
- Word processing data,
- ITS data,
- Multimedia data, and
- Real-time and static data.

An EIM&DSS must also be able to convert linear/coordinate/address matching data.

These requirements are the result of a synthesis of the literature review, team knowledge, survey input, and best practices documents submitted.

BUSINESS PROCESS DATA DRIVERS

The relationship between each of the business process requirements and the data requirements were analyzed. The results, shown in Table 13, reveal that nearly all the different types of data analysis needs are required by nearly all the different business processes and vice versa.

REVIEW BEST PRACTICES MODEL

Another approach to establishing requirements for the EIM&DSS was to synthesize a best practices model. This was accomplished by examining various environmental and transportation information management and decision support systems. Different aspects of each one was rated as follows:

- Not applicable—0,
- Does not meet—1,
- Partially meets—2,
- Meets—3,
- Exceeds—4, or
- Outstanding—5.

The best practices model was developed by taking the qualitative descriptions of all the aspects that received a score of 4 or 5 and combining them into a single idealized EIM&DSS. Table 14 presents the synthesized best practice model, which is another statement of requirements. Appendix D, provided in *NCHRP Web Document 55,* presents the raw information from which the best practices model was derived, as well as various tabulations and summaries of rating scores.

REVIEW LEGAL AND REGULATORY REQUIREMENTS AND ISSUES THAT MUST BE ADDRESSED

Historically, transportation organizations prioritized their environmental data collection needs based on legislative and regulatory mandates. Although that orientation has shifted over the past decade to an emphasis on collecting the environmental and other data that would most support proactive, environmental stewardship decisions and actions, legislative and regulatory data drivers remain an important component of state DOT and MPO environmental data collection efforts.

An EIM&DSS must have the ability to account for federal, state, and local environmental laws and regulations. All state DOTs and MPOs need to be able to comply with federal environmental laws and

Table 13. Business Process and Data Requirement Overlap

	Public Performance Reporting	Public Involvement Activities	Planning Activities	Programming Activities	Project Planning Activities	Project Design Activities	Project Construction	Mitigation/ Enhancement Activities	Operation Activities	Maintenance Activities	Closure & Decommissioning Activities	Regulatory/Policy Compliance Activities	Site Audit Activities	Exercise Simulations, Models, & Management Systems	Program/Project Evaluation	Reporting/ Data Mining Activities	Remote data entry	Data sharing	Interface with external systems	Overlap across business practices
Cost and schedule data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
Documents	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓
Linear data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Coordinate data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Address matching data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Convert linear referencing, coordinate referencing, and address matching data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Alternatives scenarios	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓		✓		✓	✓	✓
Impacts data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Permit/compliance data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Public and other agency comments	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Water issues data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Air issues data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cultural/historic data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wildlife data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Habitat data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Land use data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Noise data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mitigation data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Waste/disposal data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Socioeconomic data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Traffic data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Engineering data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Best management practices data	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
Simulation and model results	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Plan sheets		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓		✓
Geo-coded data formats	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Spreadsheet data formats	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Relational database data formats	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Word processing data formats	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ITS data formats	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Multimedia data formats	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Real-time and static data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 14. Synthesis of Best Practices Model

Category	Synthesized Best Practices
Organizations Served	Supports missions of multiple levels of transportation agencies (i.e., States, MPOs, Federal agencies, etc.).
Modes Served	Serves both passenger and freight modes, including road, rail, air, water, ITS, and telecommuting. Addresses all primary passenger modes within a multimodal/intermodal management system. Includes such actions as bike and pedestrian improvements, ridesharing, flexible work hours, transit, and telecommuting. Provides performance metrics, including outputs, outcomes, and measures of economic value based on benefit-cost calculations.
Functions Served	Supports environmental stewardship through the full range of transportation agency functions, including policy, planning, programming, project development, operations, and maintenance.
Environmental Impact	Accounts for air, soil, water, noise, wildlife/habitat, and energy impacts
Social Impact	Accounts for community cohesion, displacement, environmental justice, and accessibility of facilities and services.
Considerations	Includes relevant standards, regulations, cost/benefit analyses, and EVA considerations.
Supports Maintenance Decision Making	Addresses preservation actions, including maintenance on traveled ways, rights-of-way, and facilities, plants, and equipment.
Aids Program Decision Making	Assesses investment options and allows for the consideration of sufficient numbers of alternative packages of projects, including benefit-cost analysis. Includes management system(s) for allocating resources to specific projects based on funding availability, benefits, costs, and risk.
Useful to External Stakeholders	Helps external stakeholders, citizens, public interest groups, industry groups, and various transportation organizations to understand costs, benefits, network effects, and environmental effects. Provides design and display tools to allow stakeholders to view proposed project features.
Useful to Planning Staff	Provides a high-level planning context within a multimodal/intermodal framework for lower level project and related environmental decisions. Builds, displays, and permits analysis of various alternatives and scenarios regarding various types of transportation plans. Addresses a broad array of issues important to planners, including key environmental issues. Is consistent with strategic planning objectives and fits within planning to achieve environmental objectives and targets. Analyzes the synergistic effects of Transportation Control Measures. Useful for conducting air quality conformity analysis.
Supports Project Decision Making	Has a project information database, including environmental, social, cultural, and economic data. The project database stores individual project-level data, whether entered by the user or provided as default parameters. Linkage to CADD and design and display tools are valuable for allowing stakeholders to view proposed project features. Component design, engineering, and drafting software supports collaborative project development for all modes of transportation. Engineers can share designs, work on them together, manage and integrate updates, view spatial data on a GIS, etc. Can analyze project alternatives. Can display results of two different project alternatives side by side. Includes a project tracking system and the tracking system needs are continuously updated as the project progresses through final design and construction.
Useful to Operator Decision Makers	Includes operational issues, including heavy rail, transit, ridesharing, and ITS. Decision support system is particularly useful for assessing the effect of Transportation Control Measures (TCM) on reducing demand and improving operational efficiency.
Useful to Environmental Agencies	Addresses all salient environmental, social, and economic impacts important to regulatory agencies. Evaluates benefits, costs, and related environmental effects of transportation actions. Can provide project level design and engineering detail, maps, and environmental data that would be of interest to environmental agencies. Provides an environmental framework for continuous environmental quality improvement and reporting in a manner consistent with ISO 14001. Involves an automated workflow and approval process. Responsive to U.S. DOT, U.S. EPA and state environmental protection agency regarding processing of categorical exclusions, Findings of No Significant Impact (FONSI) and records of decisions under the NEPA process. Informs the environmental resource agency members of any changes to the environmental impacts as compared with the impacts reported in the project's Federal EIS. Reports any changes in impacts to the individual environmental resources that may occur during the pre-final and final design of the project. Helps environmental agencies see relationships between business processes and BMPs. Also, provides rationale for setting priorities.
Tracks Relevant Legislation and Regulations	Provides access to information on environmental laws and regulations. Enables users to query experts on regulatory issues. User can access online manuals. Computer-generated checklists, templates, and worksheets reflect relevant legislation and regulations.
Covers Relevant Environmental Inputs	Addresses all environmental, social, cultural, and economic issues. Queries experts on type and magnitude of different environmental impacts.
Tracks Compliance and Permit Requirements	Tracks compliance with and number and scope of federal and state permits.
Displays Schedule and Permitting Status	Includes information on permit schedule and approval deadlines.
Distributes Knowledge to Decision Makers	Easily accessible, distributed open system computing environment supports data sharing and collaboration across dispersed databases and different types of legacy systems.
Provides Alternative Selection	Builds and analyzes alternative scenarios involving different combinations of project considerations (economics, risks, priorities, environmental, etc.). Supports planning horizons up to 20 years out. Stores projects by type, location, and/or completion year.
Supports ISO 9000 & 14001	Conforms to ISO 14001 standard.
Supports Mission Strategic Objectives	Provides a strong management system framework for assessing investments and other actions that can help the agency achieve its mission of providing mobility, accessibility, and safe, efficient, environmentally sensitive transportation involving all modes. ISO 14001 framework adopted to improve business efficiency and be a catalyst for innovation. Environmental stewardship is believed to go hand in hand with efficient, productive, and environmentally sensitive business operations.
Collects and Reports Performance Metrics	Provides performance measurement, monitoring, and reporting for all modes and environmental, social, cultural and economic impacts.
Can Store and Retrieve Public Comments	Receives, stores, and retrieve citizen comments. Integrates comment review into workflow process.
Accessible to all Users	Web Interface and systems integration achieved through open distributed databases, and a data catalog with useful metadata makes information highly accessible. Templates, worksheets, and checklists are accessible by computer and may be updated and, coordinated, while tracking changes.
Intuitive and Flexible User Interface	Provides an intuitive interface that is easy to use and effective in accessing, editing, and presenting data, documents, and graphics. Also GIS capabilities allow visualization of spatial data and analysis.
Provides Knowledge Management Functions	Allows users in various locations to access and share information. Includes defined information storage schema to facilitate storage and retrieval.
Provides Useful Data Output	Provides ability to select data and presentation format according to user-defined needs. Is able to export data in standard formats.
Provides Timely Access to Current Data	Metadata provides information on data currency. Users are able to define data pushes and pulls to suit needs. Data contained within the system is available on a real-time basis. System can support decsion making based upon real-time data sources.
Provides Information on Data Quality	Extensive use of picklists for data entry to ensure data quality in addition to multiple checks of conformance with business rules. Performs edit checks.
Location Referencing	Includes means for linear and coordinate referencing. Also has conversion software. Can convert among a large number of linear and coordinate reference systems.
Document Management and Multimedia	Can store all types of multimedia, including document images, documents, designs and drawings, video, virtual reality, and results of modeling and simulation for purposes of visualization.

regulations when federal funds are involved. These federal laws will be the same from state to state.

There is also a need for a generic, flexible approach to accommodating state and local environmental laws and regulations, which vary considerably from state to state and locality to locality.

An EIM&DSS must be able to reflect the following federal environmental laws:

- American Indian Religious Freedom Act;
- Antiquities Act of 1906;
- Archaeological and Historic Preservation Act of 1974;
- Archaeological Resources Protection Act of 1979;
- Bald and Golden Eagle Protection Act;
- Clean Air Act;
- Clean Water Act;
- Coastal Zone Management Act;
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA);
- Emergency Wetlands Resources Act of 1986;
- Endangered Species Act;
- EO 11593 Protection and Enhancement of the Cultural Environment;
- EO 11990 Protection of Wetlands;
- EO 11988 Floodplain Management;
- EO 12898 Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations;
- EO 13089 Coral Reef Protection;
- Farmland Protection Policy Act;
- Federal Aid Highway Act (Section 4(f));
- Federal Insecticide, Fungicide and Rodenticide Act;
- Federal Water Pollution Control Act;
- Fish and Wildlife Coordination Act;
- Hazardous Materials Transportation Act;
- Land and Water Conservation Fund Act;
- Marine Mammal Protection Act;
- National Environmental Policy Act (NEPA);
- National Historic Preservation Act;
- National Trails System Act;
- National Wild and Scenic Rivers Act;
- Noise Control Act of 1972;
- Resource Conservation and Recovery Act (RCRA);
- Rivers and Harbors Act;

- Safe Drinking Water Act;
- Solid Waste Disposal Act;
- Surface Transportation and Uniform Relocation Assistance Act of 1987;
- Superfund Amendments and Reauthorization Act (SARA);
- Toxic Substance Control Act; and
- Wilderness Act.

Under NCHRP Project 25-23, an assessment was made regarding whether each environmental law had applicability to specific levels of decision making—planning, programming, project development, operations, and maintenance. The following conclusions were reached based on the analysis discussed in Appendix E of the research team's final report, which is available online as *NCHRP Web Document 55.*

Planning. All the federal environmental laws and corresponding regulations listed previously may be relevant to long-range, strategic, modal, policy, business, and system plans, among others.

Programming. All the federal environmental laws and corresponding regulations listed previously may be relevant to topical programs. Moreover, in the future, it is likely that the preparation of TIPs, STIPs, and transportation budgets will require increased analysis of programmatic environmental, social, cultural, and economic impacts. Currently there is no formal requirement for State DOTs and MPOs to create programmatic Environmental Impact Statements regarding their STIPs, however, the adoption of a multi-year investment program or a budget could be deemed a major action having a significant impact on the environment and require an EIS. This could trigger comprehensive data collection needs that are responsive to not only NEPA requirements but also a broad range of other programmatic legal and regulatory requirements.

Project Development. The federal environmental laws (and their corresponding regulations) listed previously are relevant at the project level, particularly project planning, project design, and to a large degree, project construction.

Operations and Maintenance. Not all, but the vast majority of the listed federal environmental laws and corresponding laws are relevant to one type of operations and maintenance activity or another. For example, the Clean Air Act is relevant to transit, aircraft, watercraft, and freight operations as well as emergency management, incident management, signal management, and traffic control involving ITS.

However, there does not appear to be a direct relationship between federal laws dealing with archeological and historic preservation and most types of operations and maintenance.

REVIEW ADDITIONAL NEEDS BASED ON JAD SESSIONS

Four regional JAD sessions were conducted to obtain input regarding requirements for the EIM&DSS. Participants in JAD sessions identified specific functional requirements as well as suggestions for screens to carry out different EIM&DSS functions.

The primary functional requirements that were identified in the JAD sessions were as follows:

- The ability to store, retrieve, correlate, and apply decision criteria to a wide variety of transportation, community, environmental and other information that can be tied to an asset, project limits, or a geographical boundary;
- A capability to monitor compliance with agency commitments, made in scoping and other public meetings, to key stakeholders regarding environmental stewardship initiatives and legal, regulatory, and policy requirements, including permits, enhancements, and mitigation actions;
- The ability to roll up environmental analysis from the project and maintenance and operations activity level to the programming or planning level or decompose program- and plan-level analysis into constituent project, maintenance, and operations impacts;
- The ability to define and analyze scenarios involving social, economic, environmental, cultural, and equity factors for alternative plans, projects, programs, and O&M activities for any mode and over various time periods;
- The ability to retrieve information regarding environmental BMPs, documents, plan sheets, and other digital objects;
- Integration with various databases, a Geographic Information System, and computer-aided design;
- Integration with various transportation and environmental simulation models, management systems, and decision support tools;

- A content management system for management of data over its lifecycle, to manage its quality, and to facilitate data sharing and inquiries regarding the nature of data;
- A workflow management system for documenting, managing, and re-engineering business processes as well as for electronic processing of approvals; and
- A customer-driven, performance-based, continuous quality improvement framework that complies with the requirements of the ISO 14001 Standard for Environmental Management Systems.

STEP 3. ABSORB THE VISION FOR THE EIM&DSS

Because the EIM&DSS must address all levels of decision making—planning, programming, project development, operations, and maintenance—for all modes, it is not easy to absorb all facets of the concept. Indeed, the concept for EIM&DSS is much like the proverbial story about the elephant that different people touch different parts of to understand. One person feels its trunk, another its back, yet another its feet, while others are feeling its legs, tail, face, underbelly, and so on. Each person develops an understanding of part of the elephant, but only by combining different views, does the concept of the elephant take form.

This implementation handbook takes a similar approach to presenting the concept for the EIM&DSS. Offered here are different views of the system that, collectively, provide a complete picture. Some views are particularly instructive, but no single view is sufficient to understand the concept. Also, different views have different value to different kinds of people who use, plan, define, develop, operate, and maintain the EIM&DSS.

The ultimate concept or vision for the EIM&DSS focuses on meeting the decision input needs of EIM&DSS customers and stakeholders. These customers and stakeholders include transportation decision makers, elected officials, citizens, public interest groups, environmental regulatory agencies, top management of transportation agencies, and managers and analysts responsible for planning, programming, project development, operations, maintenance, environmental analysis, and specific modes of transportation.

It is important for a state DOT, MPO, or other public or private agency contemplating the development of an EIM&DSS to examine each of the following views of the system carefully in order to absorb the overall vision or concept for the EIM&DSS:

- User Views—
  - View of Main Modules,
  - Use Cases and Enterprise View, and
  - GIS-centric View;

- Business Process View;

- Functional Views—
  - Diagram of Functional Elements,
  - Layers of the EIM&DSS, and
  - Role of Location Referencing;
- ISO 14001 View;
- Technical Architecture View; and
- Enterprise Database View.

In addition to the views of the EIM&DSS described here, an additional view—an object model for distributed systems—is presented under Step 5.

EXAMINE USER VIEWS

The EIM&DSS will allow various users—such as elected officials, citizens, planners, engineers, designers, environmental analysts, program managers, operations managers, and maintenance field personnel—to interact and access the system in different ways (i.e., use cases) in order to obtain relevant information and data.

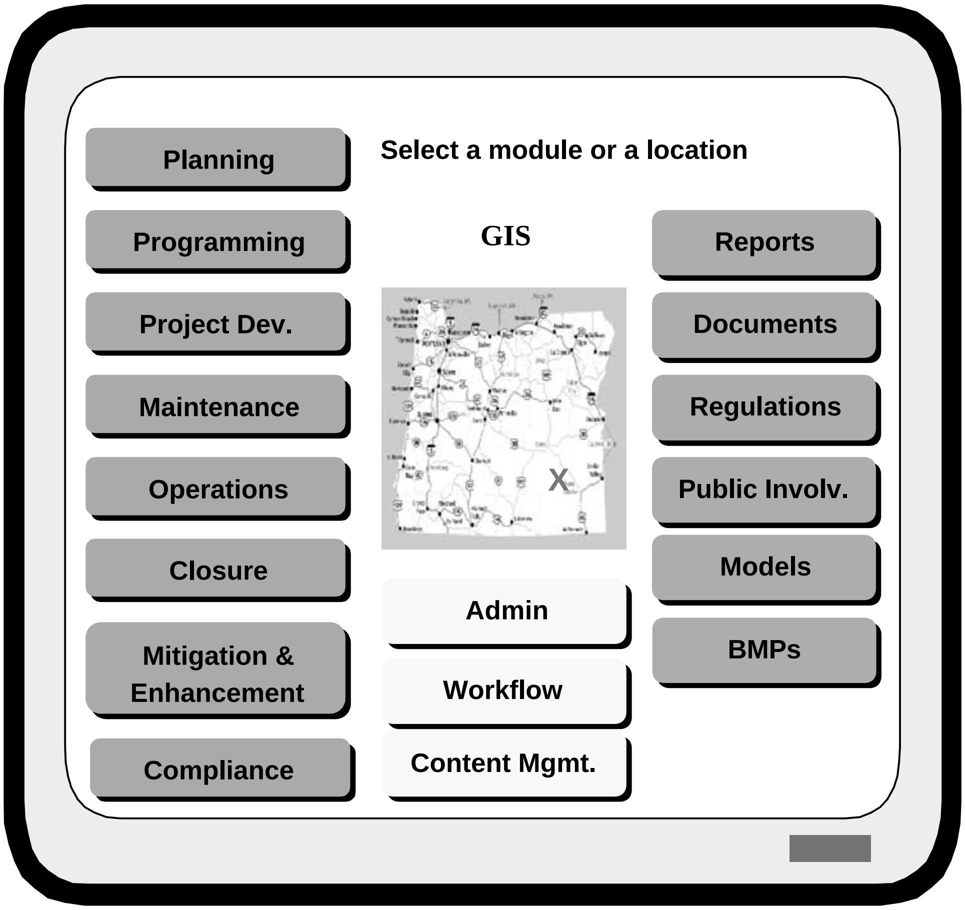
View of Main Modules

Users will be able to interface with the system in various ways. Some of these include a desktop computer, a laptop, and a personal digital assistant such as a PalmPilot. The user might activate functions of the EIM with a mouse click, keystrokes, voice recognition, a pen stylus, or other means. The user interface should be thought of as a window into real or virtual environmental enterprise databases. The user interface with the system needs to provide the flexibility to access and view the enterprise data from different perspectives, including decision-making level, the functionality the user desires to exercise, the level of detail required, security rights, and so forth.

Figure 19 presents an initial concept of the main screen for a user interface into an EIM&DSS. This view displays all the conceptual modules of the system; individual users' screens would display only those modules to which their roles and security profiles provide access. For example, if there were security that restricted certain users only to maintenance-related information, then only the Maintenance Module would be displayed.

Planning. By clicking on this module, a user would be able to display a copy of any department plan and its contents. Plans would include

Figure 19. Conceptual EIM&DSS Module Layout



draft and final strategic plans, policy plans, long-range plans, regional plans, business plans, the State Implementation Plan for conformity with air quality standards, corridor plans, and modal or intermodal/ multimodal system plans. Pollution prevention plans would also be accessible. The user would be able to obtain information about the status of the plan, its project and program composition, proposed funding sources, alternatives considered, and any plan-level environmental, social, cultural, and economic assessment of alternatives, whether a qualitative evaluation or a detailed assessment built up from information regarding specific projects and programs, such as a long-range plan air quality conformity analysis. Potential legal and regulatory compliance requirements concerning the plan would also be accessible and so would process flow diagrams for all plan-level business and approval processes. Other information that would be accessible would be relevant trends, projections, and modeling results used to generate the plan. The planning module includes the ability to exercise management systems, decision support systems, and simulation models to revise or update analysis supporting the plan. In addition, all public comments and correspondence regarding various plans would be accessible. Finally, also available would be the results of discussions with environmental regulatory agencies concerning how analysis developed at the planning level would inform lower levels of decision making, such as programming, project development, operations, and maintenance.

Programming. The programming module provides the user access to single-year and multiyear modal and multimodal/intermodal transportation programs, as well as supporting analysis, information, and data. Current and previous versions of STIPS and TIPS would be accessible and so would analysis of the conformity of STIPs and TIPs with national ambient air quality standards in non-attainment and maintenance areas. If organizations choose to analyze specific projects or subprograms included in a program, details of the transportation, environmental, social, cultural, and economic impacts of underlying projects and subprograms could be viewed in full or in summary form. The programming button would also allow users access to programmatic environmental analysis, assessments, and impact statements on specific topics (e.g., a high-speed rail program, a regional airport improvement program, a coastal inland waterway dredging program, a snow and ice control program, or a regional freeway ramp metering program). Recycling, reuse, and waste reduction programs would be accessible here. As with planning, process flow diagrams for all program-level business and approval processes could be accessed and so could public comments and correspondence on various programs and related environmental documents, such as a programmatic EIS. Management and simulation models pertinent to program-level decision making could be exercised. Results of discussions regarding how environmental analysis of programs would tier to lower levels of decision making would be readily accessible.

Project Development. After selecting this module, a user would be able select any project from a list of all projects in the department or MPO and obtain a wide variety of environmental and transportation information. Project development information would include project boundaries, descriptions, alternatives, schedules, status, permit requirements, and compliance, as well as direct, indirect, secondary, and cumulative impacts regarding environmental, social, cultural, and economic factors (assuming the information and analysis had been previously developed). Projects that are categorically excluded from a need for an environmental assessment or an environmental impact statement can be identified. Alignments, designs, and as-built plan sheets from the CADD system for various facilities (e.g., road, rail, water, air, bike, or pedestrian) would be available. Results of exercising models and simulations would be accessible and such models and simulations could be rerun to update project-level analysis. All public comment and correspondence on each project in the database can easily be retrieved. All project-level business and approval processes can be displayed. Also environmental best management practices regarding different stages of project development from planning through design and construction will be available. Information on reuse of waste materials in projects would be available (e.g., reuse of asphalt, concrete roofing shingles, glass, and coal ash in pavement surfaces, bases, subbases, and roadway embankments).

Maintenance. EIM&DSS users will be able to access a broad range of environmental data, information, and analysis regarding the maintenance of different modes. Maintenance information will cover infrastructure, facility, vehicle, and equipment maintenance. In the case of highway maintenance, environmental information will be available on all the different maintenance activities typically found in a highway program. Maintenance activities include pavement and bridge maintenance, sign work, striping and markings, guardrail repair and replacement, drainage work, vegetation management, rest area maintenance, maintenance of weigh stations, and snow and ice control. Maintenance crews and shop personnel who use chemicals will be able to access MSDSs and regulations regarding proper handling of disposal of wastes. Of the regulatory information, permits and compliance data will be available. Real-time monitoring information will be available for lead paint removal operations for steel structures that need to be repainted. Results of facility site audits will be accessible as well as pollution prevention plans for maintenance shops, yards, and facilities.

Operations. This module gives the user access to environmental information and decision support inputs for operations. Operations include real-time traffic management involving ITS, emergency response, and daily passenger and freight operations such as subways, airport terminals, and port activity. Operations may include traffic-related activities that are sometimes included in the maintenance program such as installation, repair, and replacement of signs as well as striping and marking operations. Sensors mounted on infrastructure and on vehicles, especially those that communicate via NTCIP environmental sensor station standards under the ITS National Architecture, will provide real-time information to EIM&DSS about traffic conditions, pavement temperature, and weather conditions, as well as pollution concentrations. Images from closed-circuit television (CCTV) will also be accessible. The EIM&DSS will link real-time data inputs to a wide variety of models, and results from using the models can be viewed. Business and approval processes for operations will be easily displayed. Transportation and environmental data collected in real time will be reduced and summarized in useable form for planning and other purposes. Information on environmental Best Management Practices on operations will be accessible.

Closure. The EIM&DSS will address all stages of the lifecycle of transportation facilities, including closures, decommissioning, and transfers of facilities from one jurisdiction to another. In addition to permanent closures, seasonal and emergency closures will be addressed, which can have economic and other impacts. A user who clicks on the closure button will be able to obtain detailed information regarding the closures of specific facilities, including linear infrastructure, maintenance yards, shops, and waste storage sites. Information will be available regarding alternatives considered, their environmental and other impacts, and disposal of all wastes at a site as well as remediation that has occurred or may be required. Other closure-related information will include public comments and correspondence and best management practices. News releases on closures will be accessible and temporary closure information posted on the Internet will be accessible, including any significant environmental information.

Mitigation and Enhancement. In this module, the user would be able to find out about mitigation and enhancement actions addressed in plans or programs or pertinent to projects, operations, or maintenance. For example, wetland landbank programs would be accessible here. Information would be available on wetland mitigation and enhancement plans, requirements, compliance, schedule, status, accomplishments, and coordination with environmental agencies.

Compliance. A user will be able to obtain information on compliance with environmental stewardship initiatives, commitments, regulations, permits, mitigation, and enhancement requirements. Compliance information will be accessible in many convenient ways, including by plan, program, project development, operations, maintenance, administrative unit, and location. One will be able to retrieve compliance schedules and responsibilities.

GIS. The user will be able to click on a digital map and access a Geographic Information System. All the functionality characteristic of a powerful GIS will be available to the user, including spatial display and analysis of data, dynamic segmentation, and accessing thematic geographic data. Users will not be limited to accessing data by program modules; this module will allow users to select a location and then see all relevant plans, projects, and so forth for that location. Users will be able to drill down to more detailed information.

Administration. System administrators will use this module to manage the EIM&DSS, including data rights and security procedures. Metadata will also be accessed via this button. Metadata will include information regarding the source, geographic coverage, time period, and accuracy of the data.

Workflow. The EIM&DSS will include business process flow diagrams for all levels of decision making and for related environmental, social, cultural, and economic data collection, storage, and retrieval. The workflow module will allow personnel to establish the steps of an approval process and electronically send requests for and receive approvals. The workflow management system will apply to business processes that occur entirely within an organization and to business processes that require interaction and approval with other agencies, including environmental regulatory agencies.

Content Management. This module provides information to ensure that data items entered into the EIM&DSS are worth collecting and current. The module shows who is responsible for each type of data and provides metadata (data about data). Metadata includes information on the source, geographic coverage, time period, completeness, and accuracy of the data.

Reports. The user will be able to access a wide variety of standard reports on environmental, social, cultural, and economic issues for plans, programs, projects, operations, and maintenance. In addition, users will be able to easily construct ad hoc reports using simple forms and report construction tools.

Documents. The user will be able to search, manage, and retrieve all documents stored in the EIM&DSS database or other databases that are part of a distributed system. Documents will include policies and procedures, guidelines, manuals, handbooks, training materials, reports, Material Safety Data Sheets, correspondence, memoranda of understanding, compliance agreements, public-private partnerships, and contracts. Complete document records for specific plans, programs, projects, and O&M activities will be accessible.

Regulations. Users will be able to access current federal and state laws and regulations. Regulatory information will be accessible from the EIM&DSS database, regulatory agencies, public- and private-sector information services, and environmental hotlines.

Public Involvement. A user will be able to retrieve all public involvement plans, records, and input regarding a plan, program, project, maintenance, or operations activity. The public will be able to submit comments and view lists of projects by county, zip code, or address.

Models. In this module, a user will access a menu of models, decision support systems, and management systems. It will be possible to exercise various models from the EIM&DSS, provided an application program interface or other data transfer mechanism has been established to provide input data. The user will also be able to manage the definition of scenarios and the storage and retrieval of results of developing a scenario with a particular model, decision support system, or management system. Results of one model can be passed to another model using the workflow management system. These models will be available in each program area; for example, the latest MOBILE model would be accessible here and linked to the planning and individual project modules.

BMPs. A user can access information on environmental BMPs related to each level of decision making.

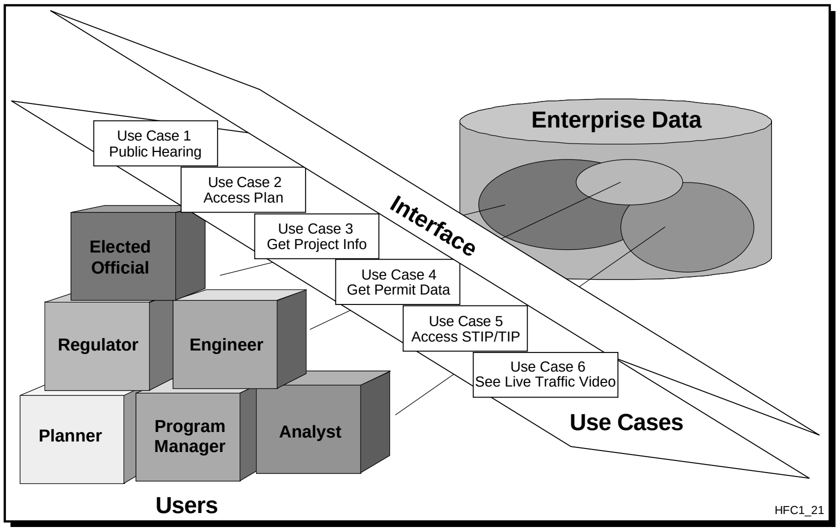
Use Cases and Enterprise View

Figure 20 shows the relationship between users, use cases, and an enterprise database. Information may actually reach specific users through distributed systems but the EIM&DSS will appear to the user as if all relevant information and data pertinent to a specific use case comes from an enterprise database. The EIM&DSS will support the full ranges of use cases described in Appendix C, provided in *NCHRP Web Document 55.*

GIS-Centric View

One of the most important views of the EIM&DSS from the standpoint of a user will be through a GIS interface. Indeed, GIS for transportation-related display and analysis of spatial data has become so important, it

Figure 20. Relationship between Users, Use Cases, and an Enterprise Data Model



has come to be known as GIS-T, which stands for GIS transportation applications. To date, a large number of agencies have implemented GIS-T. These are rich storehouses of environmental and transportation data, which can be displayed and analyzed easily. A noteworthy example is the GIS and applications developed by the University of Florida, considered by a number of DOTs to be a "best practice."

The University of Florida has a GIS center and program, called GeoPlan, partly funded by the Florida Department of Transportation. GeoPlan is not a specific software application or environmental management system; rather it is a series of activities, software, and data, including the following:

- The development, maintenance, and free dissemination of the Florida Geographic Data Library (FGDL) consisting of over 100 thematic maps as well as the development and maintenance of metadata for the FGDL;
- Development and maintenance of the GeoPlan website: http//www.geoplan.ufl.edu;
- Educational and training courses on GIS; and
- Project activities that result in specific GIS applications.

What distinguishes the GeoPlan approach from other GIS is the emphasis on developing GIS applications rather than merely being a repository for spatial data. Users throughout the state can download, from the Internet, not only GIS coverages but also selected applications. Applications require ArcView GIS software. A few of the projects and applications developed at the GeoPlan Center are as follows:

- An environmental screening analysis tool,
- A wetlands rapid assessment procedure,
- An environmental analysis and National Pollutant Discharge Elimination System (NPDES) database project ,
- An EPA southeastern landscape ecological analysis project, and
- The Florida Conservation Atlas.

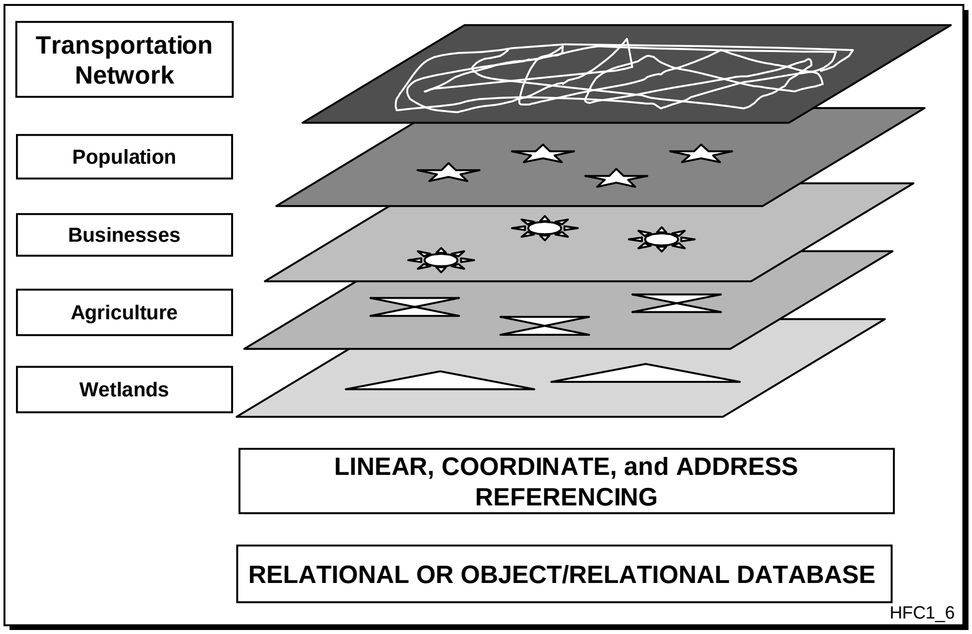
Figure 21 provides a GIS-centric view of the EIM&DSS. Frequently, the GIS will be the primary means for a user to access environmental information and perform various types of analysis. Key features of GIS-T in the context of the EIM&DSS include

- The ability to click on a location (i.e., point, line, or area) and access all plan, project, program, operations, maintenance, environmental, social, cultural, or economic information;

- The ability to display thematic data such as population, soil type, wetlands, habitat, surface water, groundwater, and air pollution levels;

- The ability to use dynamic segmentation to identify sections of a transportation network that satisfy various criteria such as

Figure 21. GIS-Centric View



presence of noxious weeds within 30 feet of the edge of a roadway, wells within 100 feet of a rail line, and sections of a waterway with high volumes of vessel traffic that cause erosion from boat wakes;

- The ability to display point, line, and area features on a map and to establish their geographic coordinates; and
- The ability to convert a line represented by geographic coordinates to a line whose endpoints are represented within a linear or address matching reference system.

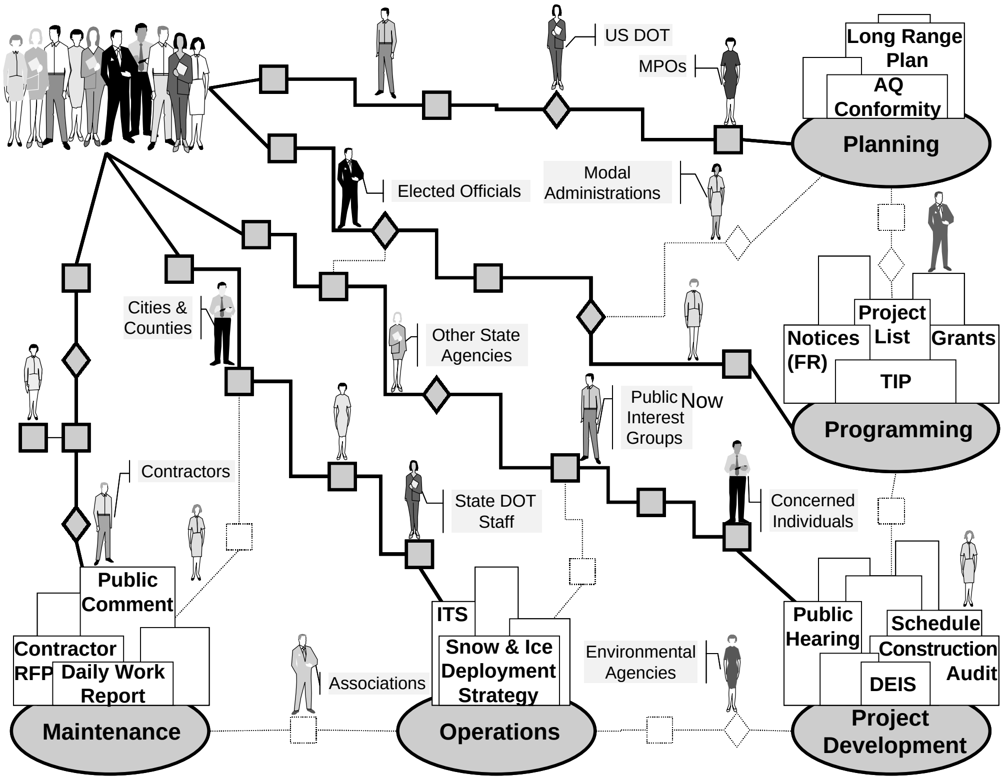
EXAMINE BUSINESS PROCESS SUPPORT VIEW

The most effective IT systems are embedded into well-constructed business processes. Using IT as a business process enabler supports reuse of data, helps to eliminate data redundancy, and reduces the duration of business processes. On the other hand, systems not embedded into a business process can hinder an organization. Frustrations build from feeding systems not helpful to the organization and when it takes more time to reconcile inconsistent data than it did to collect it, thereby detracting from the goals of the organization.

The EIM&DSS should be designed to support key business processes and the development of outputs from those processes.

Figure 22 presents a conceptual view of the EIM&DSS that shows the role of business processes in connecting a user with the types of information available for different levels of decision making: planning, programming, project development, operations, and maintenance. For example, a bridge maintenance contractor, represented by one of the figures, might need to complete an internal daily work report identifying an important environmental issue concerning a waterway over which a bridge passes. The contractor may need to access the state DOT’s EIM&DSS regarding best practices for addressing water quality at sites similar to the one on which he/she is working. The EIM&DSS would support a large number of specific business processes, including those listed and presented under Step 2, “Understand Requirements for the EIM&DSS.” Many of these business processes often would involve one or more internal or external approval steps, and approvals would be processed electronically using a workflow management system.

Figure 22. Users, Business Processes, and Outputs



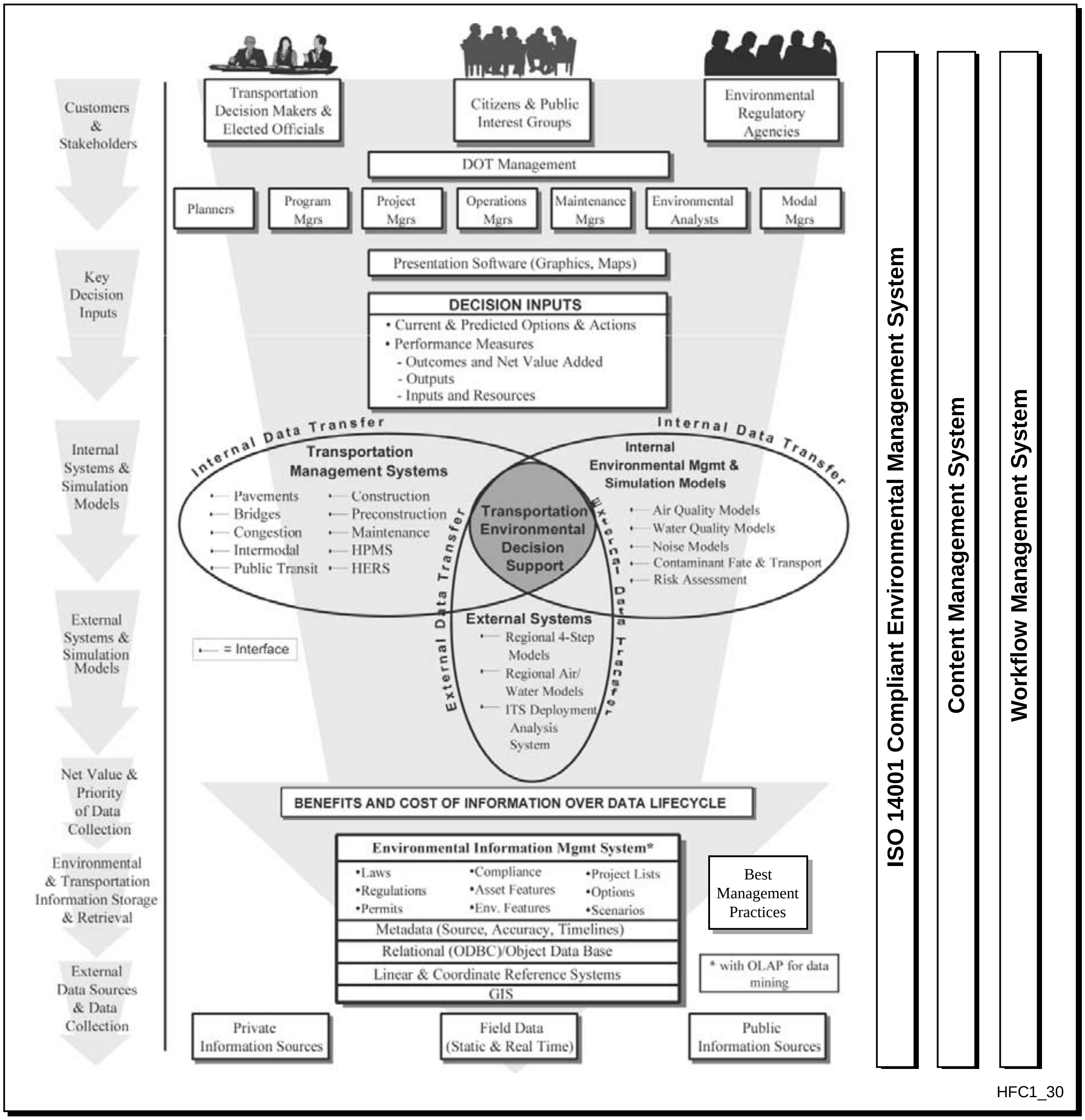
REVIEW FUNCTIONAL VIEWS

Presented here are three views of the functional elements of the EIM&DSS. Each functional element shown in a particular view represents a conceptual functional building block. The exact manner in which the functionality would be provided has not been determined. The functionality might be provided in many different ways. Not every functional requirement has a corresponding functional element presented in these views. For example, the functional requirement that the EIM&DSS serve the planning process is not represented by a functional building block called “planning process.” Instead multiple functional elements taken together provide the functionality planners require.

FUNCTIONAL ELEMENTS OF EIM&DSS

The first view of key functional elements of the EIM&DSS is presented as Figure 23, which includes most of the functional elements shown in Figure 7. The discussion regarding Figure 7 focused on the customer-driven, top-down approach to requirements analysis. Here the focus of the discussion is on the functionality of the system.

Figure 23. Functional Elements of EIM&DSS



The following is a brief description of each functional element:

Presentation Software (Graphics, Maps, and Other Visualization Tools). This functional element provides the means for users, customers, and stakeholders, to see the system outputs presented in useful and attractive ways. This functional element includes standard presentation software that is commonly found in commercial office-suite software. Such presentation software includes the ability to combine graphics, images, spreadsheets, audio, and video in a series of electronic slides that can be used in a wide variety of informational and decision-making settings. In addition, presentation software would include other presentation and visualization tools such as GIS, 3D images, animation tools, and virtual reality. For example, the Chief Executive Officer may wish to show an environmental legislative committee a map with all maintenance facilities that are in compliance with the state environmental agency's NPDES permits. Another example would be a bridge engineer who wishes to use virtual reality software to see how a containment structure for lead-based paint removal will look from the standpoint of a lead paint removal contractor working both inside and outside the containment structure. The bridge engineer may need data on internal air and external air, water, and soil lead concentrations. Predicted levels throughout the containment area and around the bridge structure would be combined with the virtual reality images to enhance understanding of how containment design and operation affects lead levels.

Decision Inputs. A functional element of the EIM&DSS consists of software that produces decision inputs for managers, administrators, elected officials, and other decision makers. These decision inputs consist of various quantitative and qualitative information—direct, indirect, and cumulative impacts—for each alternative being considered, whether it applies to planning, programming, project development, operations, or maintenance. The quantitative inputs consist of current and predicted performance measures that fall into the following categories:

- **Outcomes—**The results or impacts of implementing an option or taking an action (e.g., increased species diversity, pollution reduction, increased incomes for minorities, and improved mobility or accessibility). Outcomes include changes in value-added measures (e.g., net discounted benefits, cost-benefit ratio, avoidable lifecycle costs, and user and external costs).

- **Outputs—**A measure of the level of production (e.g., number of lane miles of road built, number of acres of new landscaping, and number of acres of wetlands restored)

- **Inputs—**The resources used in undertaking the option or action (e.g., energy, land, labor, equipment, materials, and dollars).

Interfaces with Transportation Management Systems. A functional element of the EIM&DSS includes the transportation management systems found in transportation agencies and MPOs. These transportation management systems may be directly incorporated into the EIM&DSS but more likely would be part of the EIM&DSS by virtue of interfaces. The types of management systems that may be part of this functional building block are as follows:

- Pavement Management System,
- Bridge Management System,
- Congestion Management System,
- Intermodal Management System,
- Public Transit Management System,
- Safety Management System,
- Maintenance Management System,
- Preconstruction Management System,
- Construction Management System,
- Project Tracking Management System,
- Highway Economic Requirements System, and
- Highway Performance Monitoring System.

Many of these systems may also be properly thought of as decision support systems and may include simulation and optimization procedures.

Interfaces with Environmental Management Simulation Models. Another functional element consists of interfaces with transportation and environmental simulation models that can be exercised within the EIM&DSS. Examples of these simulation models include

- Standard 4-step transportation models that address trip generation, distribution, mode split, and route assignment;
- Rail, air, bus, and waterborne traffic simulation models;
- Air pollution emission and pollution concentration models;
- Noise pollution models;
- Water pollution models;
- Contaminant fate and transport models;
- Vegetation succession or habitat change models;
- Economic development models; and
- Land use models.

Internal Telecommunications. To enable users to access transportation management systems and models within their own organization, there needs to be an internal communication system such as an intranet with connections to systems. This is an essential functional element of the EIM&DSS.

External Telecommunications. To allow users to access models and systems outside their organization, there needs to be external communications such as the Internet, extranets, telephone connections, virtual private networks, etc. This functional element needs to be present to allow agencies access to modeling tools in other organizations. In the future, application services providers (ASPs) on the Internet will provide an increasing amount of the analytic capability that transportation agencies require.

Environmental Information Management System. This functional element allows the storage and retrieval of environmental, social, cultural, and economic data and information pertinent to each level of decision making and each mode of transport. The EIM system includes a linear and coordinate reference system and a means of converting among reference systems, as well as metadata and the GIS. The database may be relational or object/relational and, therefore, can store alphanumeric information or digital objects such as documents, images, audio, video, and CADD files. The kinds of information found in the EIM system include

- Plan-level data;
- Program data;
- Project data;
- Operations data;
- Maintenance data;
- Closure data;
- Descriptions of alternatives and scenarios and corresponding environmental, social, cultural, and economic (ESCE) impact data;
- Permit data;
- Compliance data; and
- Environmental laws and regulations.

Online Analytic Processing (OLAP). One of the functional elements of the EIM&DSS is the ability to analyze the data and information in the database in a wide variety of different ways. These analytic tools include statistical analysis packages and data visualization tools.

Interface with Public- and Private-Sector Data Sources. The EIM&DSS will have the ability to connect or interface with a wide variety of public- and private-sector data sources. For the most part, this will be over the Internet. One challenge in implementing the EIM&DSS will be to identify these potential data sources. Once identified, data analysis must be conducted to map the source data to the EIM&DSS data structure; this task may also include the creation of translator software to connect the two systems.

Interface with Real-Time Data. There will be a functional element that makes real-time transportation and environmental data available to EIM&DSS users. Real-time data will become increasingly important for operations management. Examples are data from Road and Weather Information Systems (RWIS) and environmental and other sensors on vehicles.

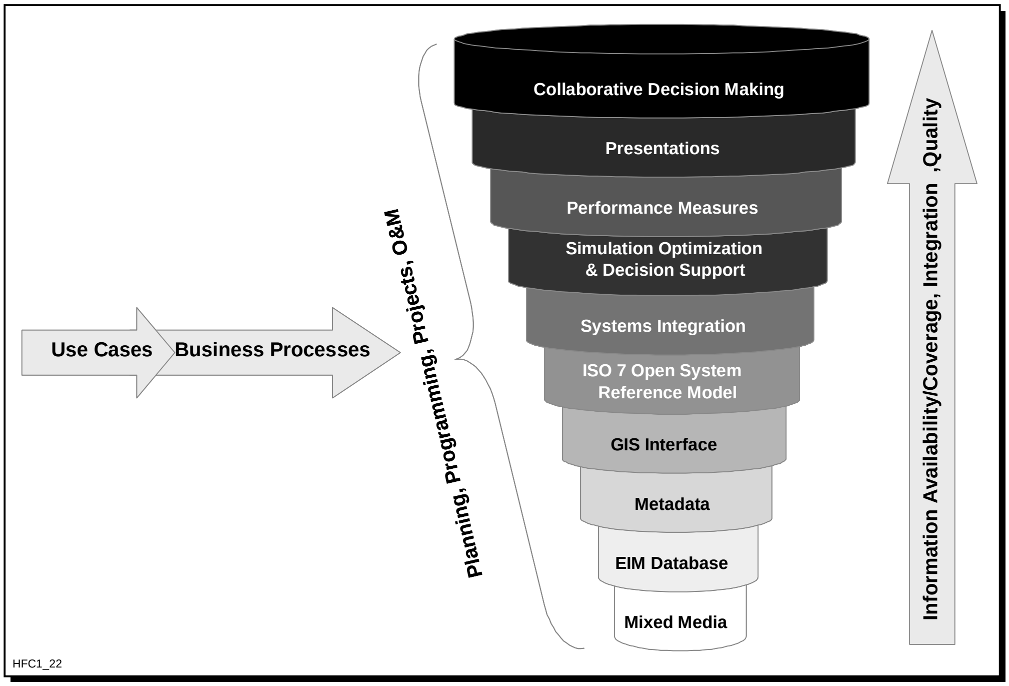
Content Management System. The EIM&DSS includes functionality that allows the management of system content. Users will be able to control entry, updates, and deletions of information for which they are responsible; access tools for assessing the benefits and costs of collecting and managing data over the data lifecycle; and be able to view metadata within the system. Metadata will describe who is responsible for the data, when the data was collected, the coverage and quality of the data, and other useful information about the data.

Workflow Management System. This functional element allows the user to define, view, and revise business processes, including any internal or external approval steps that are required.

Layers of the EIM&DSS

This view of the EIM&DSS is conceived as a series of layers (Figure 24) that provides increased information availability, coverage, integration, and quality as one rises from the bottom to the top layer. This view is also suggestive of the evolutionary path of the EIM&DSS, which is more fully addressed under Step 6, "Identify Alternative Migration Paths." Once specific layers are implemented, they become accessible under various use cases and business processes. The layers also serve all levels of decision making—planning, programming, project development, operations, and maintenance.

Figure 24. Layers of the EIM&DSS



Mixed-Media Layer. The most rudimentary and least evolved layer of the EIM&DSS is the diverse and disparate data that exists in many forms and media throughout an agency. This data consists of paper files, electronic files on the hard drives of individual computers, files on mainframes, and video stored on shelves in the training library.

EIM Database Layer. The second layer consists of the EIS database. Early stages of implementation would involve using a relational open database connectivity (ODBC) compliant database to store certain types of environmental information, but eventually this second layer would become a rich database that stores all types of environmental, social, cultural, and economic data, and other types of environmental management information. In addition, data and information in all major types of media would be stored and accessible within this layer.

Metadata Layer. The third layer is the metadata, which would include information on the source, updating responsibility, time coverage, spatial coverage, and quality of the data or information in the EIM database. Metadata might also include information on intellectual property rights and terms and conditions of use, especially if the information comes from a private-sector source. Other metadata would include geographic projections (e.g., NAD 87 and state plane coordinates) of the digital base map, accuracy of digital maps, and the accuracy of Global Positioning System (GPS) waypoints used to establish linear infrastructure (e.g., a highway centerline).

GIS Interface Layer. The fourth layer is the GIS interface that permits the display, manipulation, and analysis of spatial data. The GIS cannot be implemented without the EIM layer and should not be implemented without the establishment of metadata.

ISO 7 Open System Reference Layer. The fifth layer consists of communication standards that allow the sending and receiving of data to and from the EIM&DSS. Data will be exchanged among users and systems. Without this layer, databases in desktops, minicomputers and mainframes remain islands, and there is no ability to exchange data needed for environmental management and decision support. This communications layer will typically conform to the seven-layer ISO Open Systems Interconnection Reference Model. This standard model forms the basis of telecommunications interconnections throughout the world, including the Transmission Control Protocol/Internet Protocol (TCP/IP) and has the following seven layers: a physical layer, a data link layer, a network layer, a transport layer, a session layer, a presentation layer, and an application layer.

Systems Integration Layer. The sixth layer is systems integration. Even if communication standards and protocols exist, there need to be application program interfaces and open database exchange standards such as ODBC and Java database connectivity (JDBC) to allow data to be passed back and forth among systems and databases. In the Internet environment, this type of data exchange will be facilitated in the future by the Extensible Markup Language (XML) and Simplified Object Access Protocol (SOAP). (System architectures involving distributed processing facilitated by XML and SOAP are discussed in Step 5.)

Simulation, Optimization, and Decision Support Layer. The seventh layer consists of simulation, optimization, and other sophisticated decision support tools that can be used to make projections of ESCE impacts and optimally allocate funds among competing projects or actions. When this layer is fully implemented, it will be possible to use the EIM&DSS to extract data from the EIM database or from other related systems and exercise various simulation models and decision support systems in order to analyze alternatives or scenarios.

Performance Measurement Layer. The eighth layer is the performance measurement layer. This layer provides the decision inputs to decision makers. As discussed above, these decision inputs consist of quantitative and qualitative information and analysis. The quantitative information consists of various types of quantitative measures—value added, outcomes, outputs, and resources used for various alternatives or scenarios under consideration.

Presentation Layer. The ninth layer is the presentation layer. This layer takes information either directly from the EIM database or from the simulation and decision support layer and packages it in useful, attractive presentation formats. The purpose of the presentation layer is to provide the right data, at the right time, in the right format, tailored to the right audience so as to be of maximum use in analyzing an alternative or making a decision.

Collaborative Decision-Making Layer. The tenth and final layer, represents the ultimate evolution of the system from a functional standpoint. When this and all the preceding layers have been implemented, the EIM&DSS will support collaborative planning, programming, project development, operations, and maintenance decision making. This layer will integrate CADD, 3D animation, virtual reality, and complex simulation, optimization, and decision support tools that allow users to experience simulations in a rich visual or multi-sensory environment, work in groups, and collectively make decisions most likely to maximize net transportation and environmental benefits over time. These tools will be especially powerful for work groups involved in planning and design (e.g., context-sensitive design), meetings with top managers and chief administrative officers where important decision must be made, public meetings, and legislative hearings.

Figure 25 provides a more detailed look at the data, business process, and technology elements that constitute an EIM&DSS and represents another way of looking at the building blocks that constitute the desired EIM&DSS end state.

Role of Location Referencing in the EIM&DSS

Figure 26 highlights the central role that location referencing plays in knitting the EIM&DSS into a cohesive system. Location referencing allows a person to identify locations in terms of linear, coordinate, and address referencing systems and anchors representations of physical things stored in the database to ground truth in the real world. The location referencing capabilities of the EIM&DSS also include the means for converting among different reference systems.

M METHOD Rigorous

Figure 25. Building Blocks to Collaborative Decision Making and Workflow Management

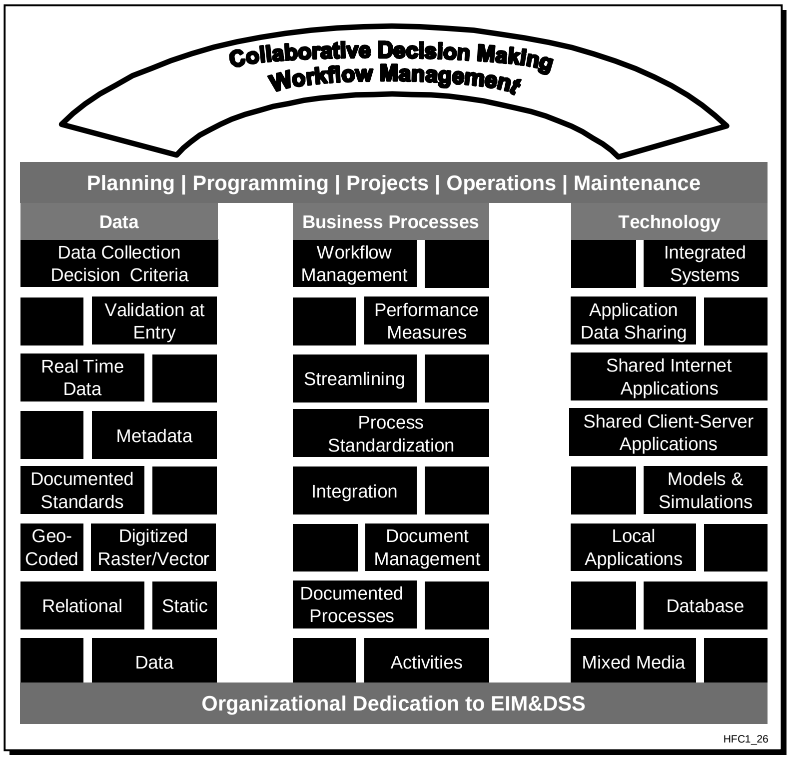
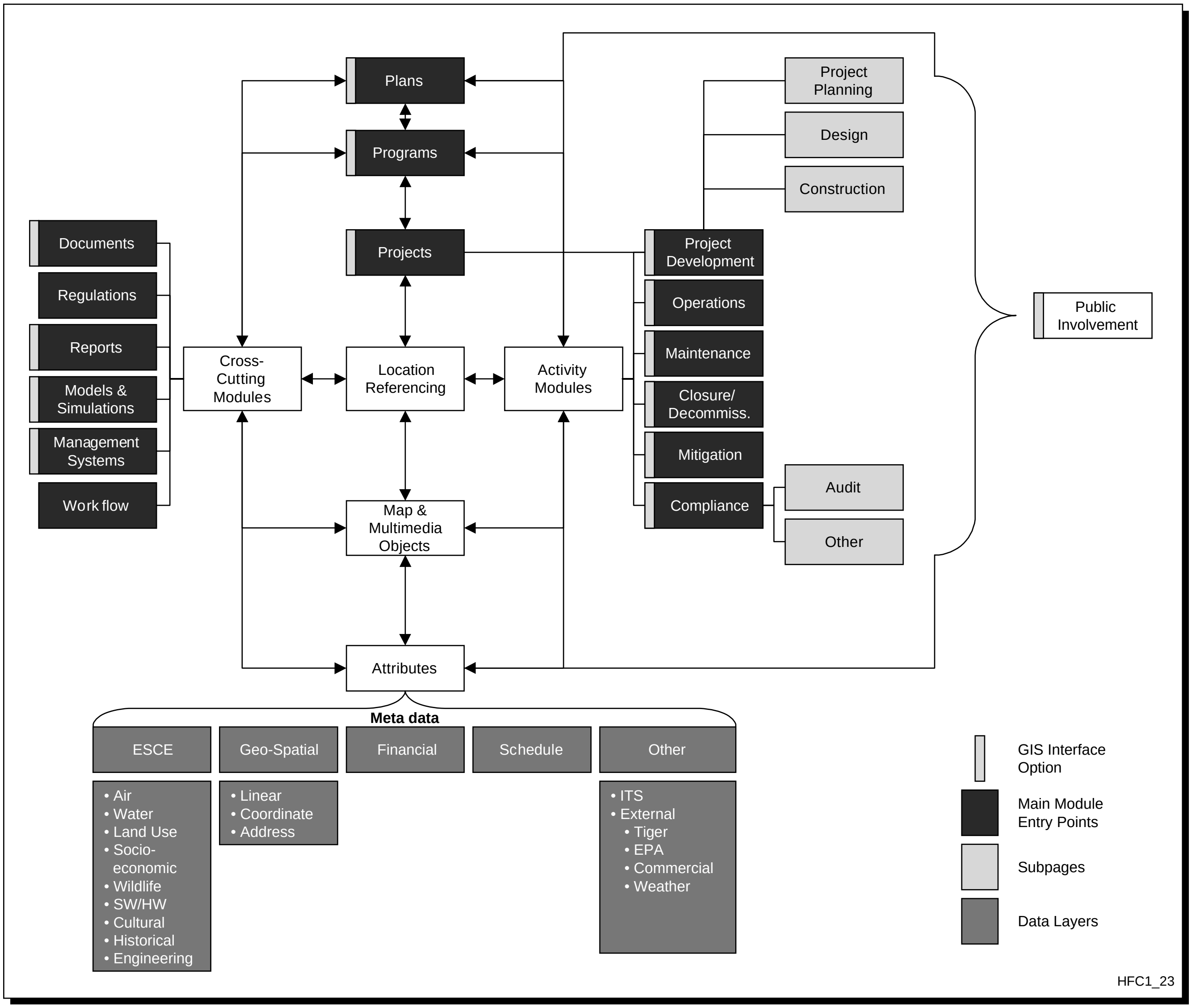


Figure 26 can best be interpreted by understanding how the top, bottom, right, and left portions of the diagram relate to the location-referencing systems within the EIM&DSS and to the functionality that can be exercised from the main module, in particular each of the buttons on the main menu of the system (see Figure 19 presented earlier).

Top of Diagram. Projects, programs, and plans are related partly through the location of projects. Each project will have location identification in terms of linear and coordinate reference systems. Project endpoints or boundary areas will be identified. In addition other location referencing consistent with more common or colloquial ways of identifying project end points or boundaries will be available, (e.g., the intersection of Interstate Highway 95 and U.S. Highway 1). A multiyear program will have locational boundaries such as a metropolitan region or a state and all the projects in such a program can be identified partly by location. Subprograms will be located (e.g., a general aviation airport noise reduction program would identify the locations of all such airports and the surrounding areas potentially affected by aircraft noise). Location referencing would also be used to

Figure 26. Role of Location Referencing and GIS in Exercising Functionality and Accessing Data



identify a plan's boundary and the boundaries or locations of all programs and projects included in a plan.

Bottom of Diagram. In many cases, location referencing will be indispensable to accessing many digital objects, especially maps and linear logs, but also digital objects associated with infrastructure, vehicles, and equipment. In addition, if one wishes to access information regarding environmental, physical, safety, or other attributes of a segment of infrastructure—such as a section of road, track, or waterway—location referencing will be necessary to identify the section of interest. Attributes that can be referenced by the system include, but are not limited to

- ESCE,
- Geo-Spatial,
- Financial,
- Schedule, and
- Other.

Left Side of Diagram. Many elements of the EIM&DSS have uses that cut across different use cases, business processes, and levels of decision making. Such elements include documents, reports, information on regulations, models and simulations, management systems, and workflow management. Location referencing will mediate between EIM&DSS users and these different functional elements. For example, a planner may want to retrieve a document that is a preliminary environmental assessment of alternative corridor improvements. The most convenient way to retrieve this document might be through identifying the corridor location and then identifying what documents are available regarding that corridor.

Right Side of Diagram. A large number of transportation actions with environmental ramifications are simply actions that pertain to project development, operations, maintenance, closure/decommissioning, mitigation, and compliance. For example, state maintenance programs include a large number of different actions ranging from snow and ice control to ditch cleaning to patching potholes to repairing guardrail. Many maintenance superintendents schedule these activities biweekly or weekly and then make daily assignments of labor, equipment, and materials to specific activities and specific locations. When maintenance work is completed, crew leaders fill out a daily work report describing the activities performed, the location of work, the outputs and outcomes, and resources used. Similarly construction activities—regardless of whether for transit, highway, rail, pedestrian, or bike—require the contractor to know the exact location where the work will occur. Furthermore, construction inspectors complete “Inspector Daily Reports” that have detailed location information and the quantity of bid items used. Finally, mitigation and compliance activities normally will be tied to specific locations. An auditor wanting to know whether there are problems with leaky underground tanks at fuel facilities will want to access all fuel facilities by location.

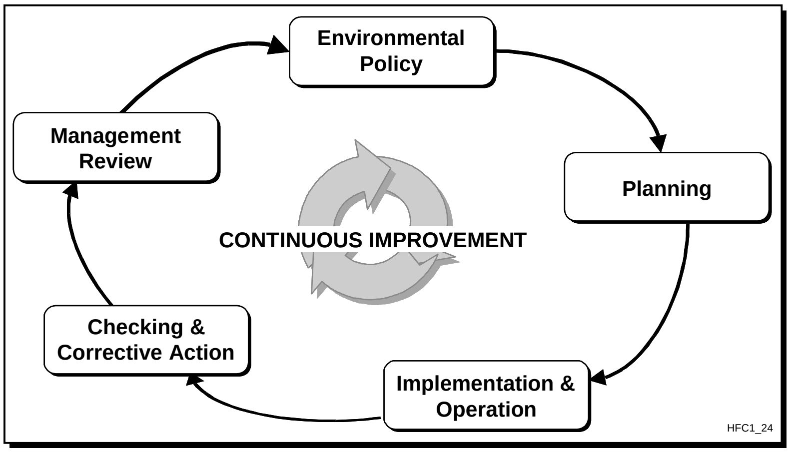
GIS plays a crucial role along with location referencing in allowing users to exercise different types of functionality within the EIM&DSS. Places where a GIS interface is important are shown in Figure 26 by a GIS interface extension.

EXAMINE ISO 14001 VIEW

The EIM&DSS is consistent with ISO 14001 standard for Environmental Management Systems illustrated in Figure 27. Since the ISO 14001 standard conforms to the "Plan, Do, Check, Act" cycle of continuous improvement, the EIM&DSS will also conform to the ISO 9000 standard for quality management system (Whitelaw, 1998).

Perhaps the most important benefit of implementing ISO 14001 in conjunction with the EIM&DSS is that it provides the agency with an overall environmental performance measurement framework. This framework can be integrated into a broader performance-based planning process, provide a basis for establishing environmental performance targets, and provide the information for an annual report to management and the public.

Figure 27. Environmental Management System Model for the ISO 14001 International Standard



Under the ISO 14001 standard, the organization must establish and maintain an EMS that satisfies the following requirements.

METHOD Rigorous

Environmental Policy

Top management must define an environmental policy that

- Fits the nature, scale, and impacts of the organization's activities, products, and services;
- Commits the organization to continual improvement and pollution prevention;
- Complies with environmental laws and regulations;

- Offers a framework for establishing and periodically reviewing environmental objectives and targets;
- Provides for documentation, implementation, maintenance and communication to all employees; and
- Is accessible to the public.

Planning

The organization must plan so that it fully addresses the following:

- Environmental aspects of its operations, activities, services or products that affect the environment;
- Legal and other requirements pertinent to the environmental aspects; and
- Objectives and targets for each pertinent function and level in the organization consistent with the organization's environmental policy and contributing to pollution prevention.

Implementation and Operation

The organization must implement an environmental management program for achieving the organization's environmental objectives and targets. The management program must address responsibilities, resources (e.g., human resources, skills, technology, and financial resources), and timeframe or schedule. The implementation and operation approach must also address training, communication, system documentation, document control, operational control, and emergency preparedness and response.

Checking and Corrective Action

The organization must periodically monitor and measure environmental performance, track the effectiveness of its controls, and assess progress in attaining environmental objectives and targets. The organization is required to establish and maintain procedures for addressing non-conformance and taking corrective and preventive action. The organization must maintain records concerning environmental matters and periodically conduct an environmental management system audit.

Management Review

The EMS is required to have a management review process to assess its suitability, adequacy, and effectiveness over time, and to address needs for changes to policy, objectives, and other elements of the system in light of the commitment to continuous improvement (Cascio, 1996)

LOOK AT KEY PARTS OF DATA MODEL

Within an enterprise such as a DOT or an MPO there is typically a core set of data needed to support the business processes performed by the organization. By defining those core data elements and the relationships between them, an organization establishes an enterprise data model, also known as an entity relationship diagram (ERD). This enterprise data model pertains to that part of the EIM&DSS which is the EIM system. **The EIM system cannot be completely specified until the decision inputs are defined. These decision inputs include the direct, indirect, and cumulative transportation, social, economic, environmental, cultural, and other impacts for each alternative and scenario that is addressed at a particular level of decision making.**

Once an enterprise data model is defined, metadata for each data field in the model can be defined. The benefit of an enterprise data model is that data are organized and integrated within the context of the entire enterprise, rather than within a single business process. More specifically, an enterprise data model provides the following benefits:

- Reuse of data across business processes,
- Minimization of time spent understanding and resolving data inconsistencies across systems,
- Reduction in cycle time for product development involving data, and
- Significant progress toward knowledge management within an organization.

Integration needs across systems and business processes determine the size of the enterprise data model. Simply stated, if data systems contain data that supports a common business process or feeds into a related business process, the related data should be a part of the same enterprise data model, and, therefore, be integrated with each other. The enterprise data model presented here assumes that eventually the agency will achieve all the systems integration required in order to satisfy the EIM&DSS requirements.

Important issues concerning an enterprise data model are as follows:

- Should each state define its own enterprise data model?
- Should there be a generic enterprise data model each state can customize?
- Can a standard model be developed that each state can augment with additional tables?

Under NCHRP Project 25-23, a high-level entity relationship diagram (e.g., enterprise data model) was developed that each state can adapt to its own needs. The data model involves the definition of entities corresponding to tables in a relational database. The entities represent a complete (or nearly complete) set of relational database tables needed to satisfy the functional and other requirements for the EIM&DSS. The entity relationship diagram also establishes the relationships between entities (e.g., one to one or one to many). Important, representative attributes for each entity are also established. The attributes for each entity are not complete and would be established in future implementation projects.

Indeed the enterprise data model (i.e., entity relationship diagram) discussed here is a starting point for a more fully specified data model in the evolution of a fully functioning EIM&DSS.

Figures 28a, 28b, 28c, and 28d present the enterprise data model in four parts. Definitions of entities and a more detailed Entity Relationship Diagram can be found in Appendix F, contained in *NCHRP Web Document 55*. The four parts are as follows:

1. **Plan, Program, Project, Operations and Maintenance (PPP&OM) Identification—**A core portion of the EIM&DSS is the ability to uniquely define a plan, program, project, operations activity, or maintenance activity; define a specific time frame for each of these; define the responsible agency (i.e., owner agency); and establish what environmental issues or areas are associated with a particular phase of a transportation activity.
2. **Location Referencing—**This portion of the data model ensures that a linear or coordinate referencing system can be used to establish the location of any plan, program, project, operations, or maintenance activity, as well as any transportation or ESCE factor for any point or any link of a network. Sufficient points on the network (e.g., endpoints of a section of road) are tied to

Figure 28a. EIM&DSS ERD Subject Area—PPP and OM Object Identification

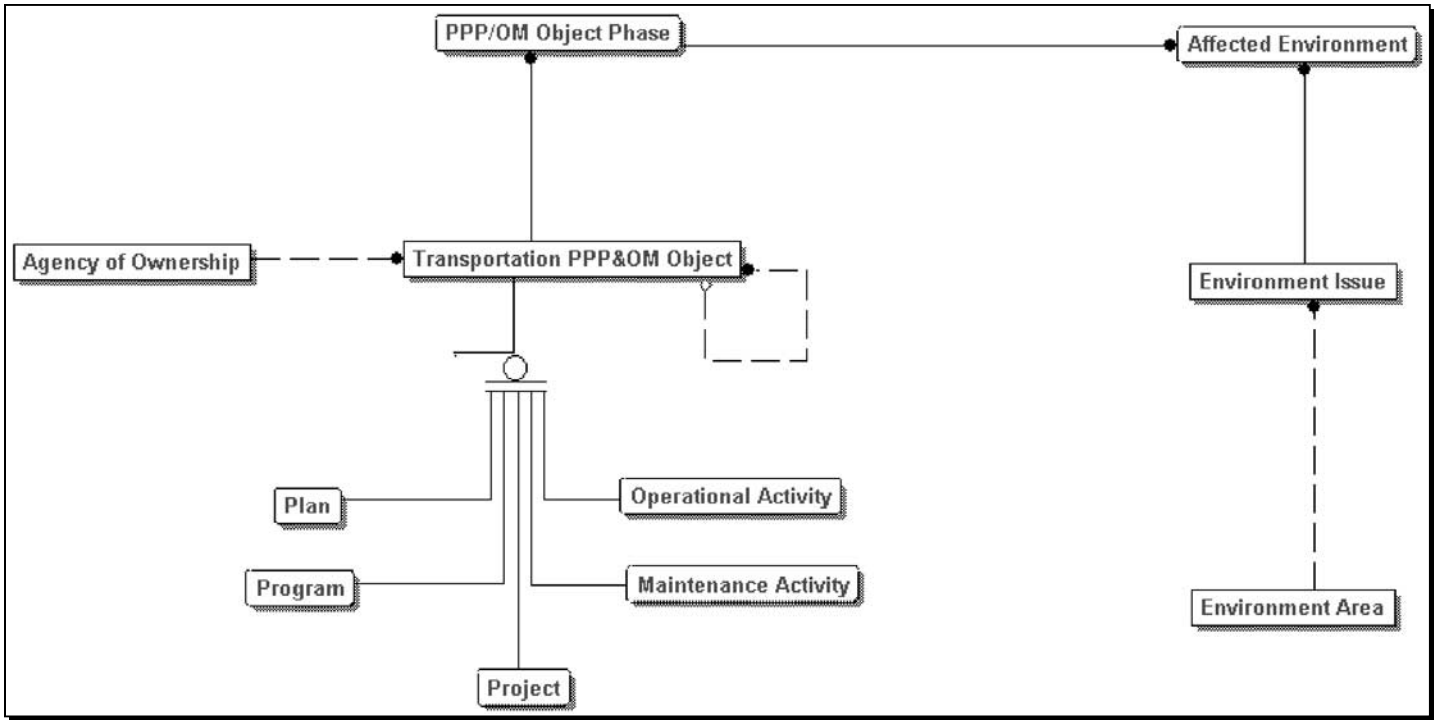


Figure 28b. EIM&DSS ERD Subject Area—Location Referencing

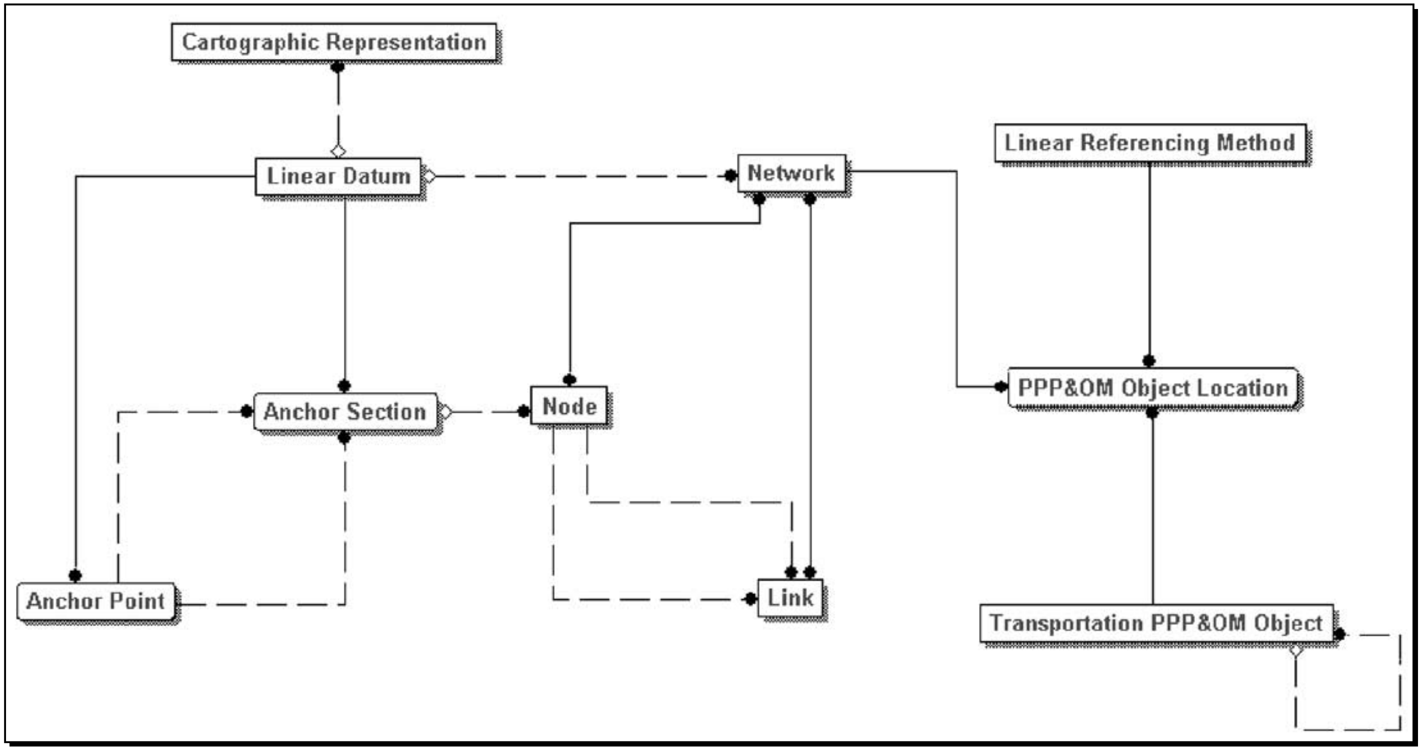


Figure 28c. EIM&DSS ERD Subject Area—Decision Support

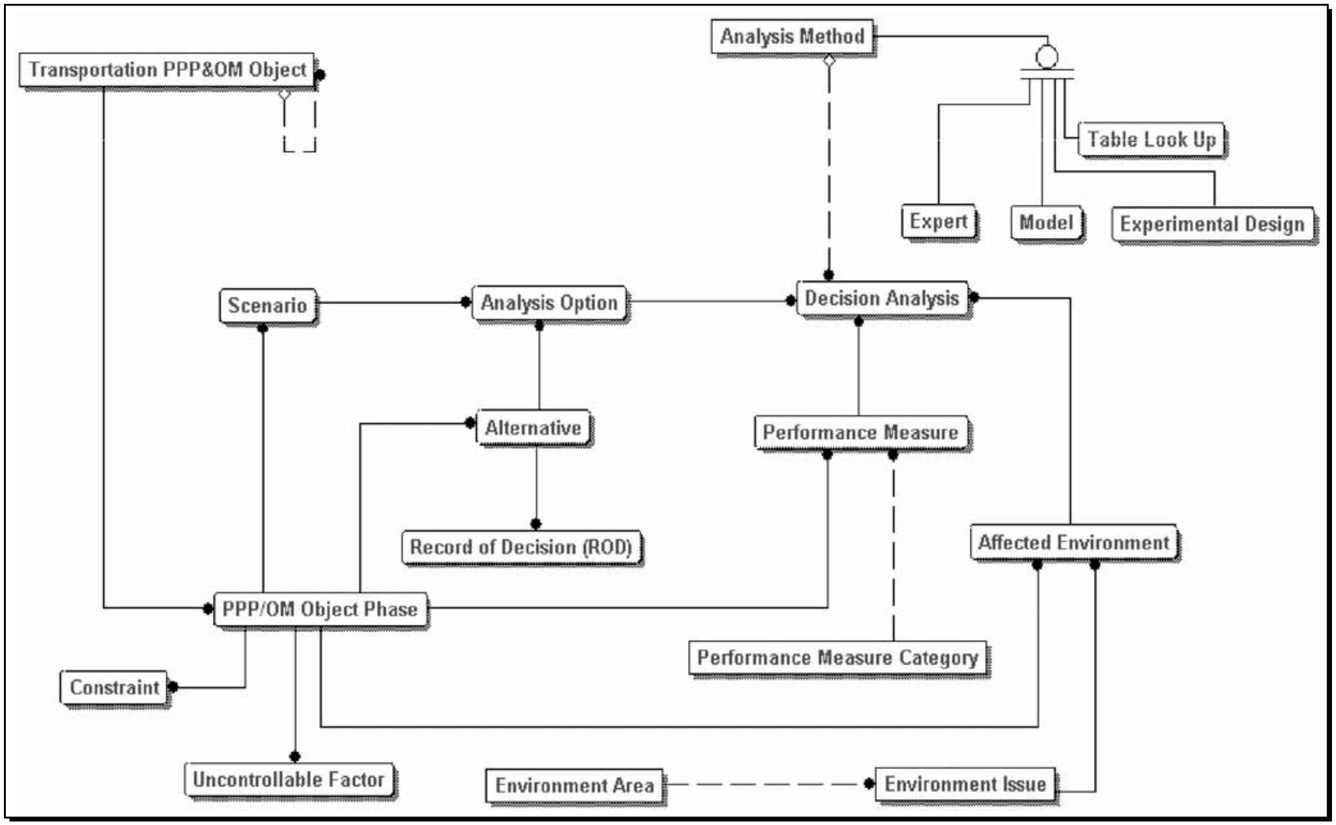
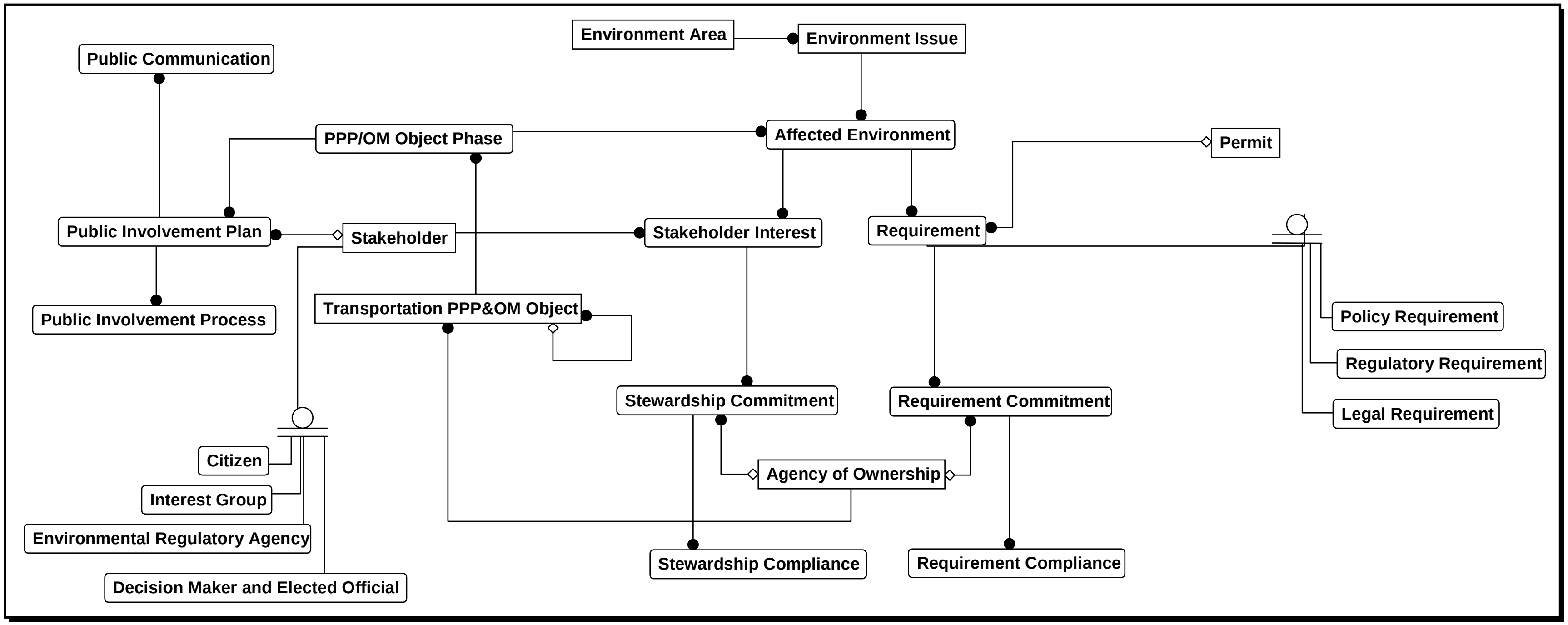


Figure 28d. EIM&DSS ERD Subject Area—Stakeholders Interest, Agency Commitments, and Compliance



ground truth (also known as anchors that have a high degree of locational accuracy and statistical confidence). The location referencing procedures allow for alternative methods of cartographic representation (e.g., latitude-longitude, state plane, and NAD 83) and linear referencing (e.g., mile point, county-route-mile point, and kilometers).

3. **Decision Support—**Agency staff can define transportation and environmental performance measures in numerous different ways relevant to a specific agency or a particular issue. These measures include standard direct, indirect, and cumulative social, economic, environmental, cultural, and other factors; measures of value added, outcomes, outputs, and inputs; and balanced scorecard categories consisting of customer-oriented, financial, internal, innovation, and learning. Measures can be defined for alternatives or scenarios. It is also possible to define constraints and uncontrollable factors. The EIM&DSS supports four broad categories of analysis: (1) analysis performed by experts, (2) exercising models, (3) table look-ups, and (4) experimental designs.
4. **Stakeholder Interests, Agency Commitments, and Compliance—**For each phase (e.g., planning, programming, project development, operations, or maintenance), one can establish stakeholder interests, develop a public involvement plan, and manage communications with each type of stakeholder. In addition, one can track handoffs in responsibility for compliance with stewardship or formal commitments (e.g., regulatory, policy, and legal) in response to decisions reached in scoping meetings and with regard to alternatives or specific environmental issues under investigation.

Listings of Plans, Programs, Projects, Operations, and Maintenance Activities

A well-designed enterprise data model once implemented in an EIM&DSS will allow a user to display a list of all plans, programs, projects, operations, and maintenance activities of a DOT or an MPO, and select any one on which to obtain more detail. Table 15 illustrates such a master list. There is a unique identification number for each plan, program, project, and operations or maintenance activity. There is also an identifier of alternative plans, programs, projects, and so forth, where appropriate. The date of the last version of the plan, alternative or scenario is presented, and if available the dates of the

Table 15. Listing of Plans, Programs, Projects, Operations, and Maintenance Activities in EIM&DSS

Name of Project, Plan, Program, or M&O Activity	Identification No.	Alternative Identifier	Date of Last Version/ Scenario	Dates of Previous Version/ Scenario	Name of Plan in Which Included	Modes
Projects						
Sampson Bridge Rehab Project	H-P-J-1234567890	Alt 1	02/13/99	N/A	Long Range Plan	Highway
		Alt 2	02/14/99	N/A	Long Range Plan	Highway
		Alt 3	02/13/99	N/A	Long Range Plan	Highway
		Alt 4	02/13/99	N/A	Long Range Plan	Highway
		Alt 5	02/17/99	N/A	Long Range Plan	Highway
Northwest Highway Connection	H-P-J-2345678901	Alt2	04/01/01	12/7/00	Long Range Plan	Highway
Downtown Transit Terminal	T-P-J-3456789012	Alt7	04/22/01	04/08/99	Long Range Plan	Transit
Plans						
Long Range Plan	LRP-1	Alt 1	02/23/02	N/A		
		Alt 2	02/30/02	N/A		
Rail Plan	RP-123	Alt 1	12/09/00	N/A	Long Range Plan	Rail
Strategic Plan	SP-2	Alt 1	06/05/01	06/13/96	A	ll Modes
I-95 Corridor Advance Traveler Information System	A-11111111111	Alt 1	09/13/01	08/29/00	Long Range Plan	Highway
Programs						
State Transportation Improvement Program	STIP-2	Alt 1	02/15/02	01/03/01	A	ll Modes
		Alt 2	02/15/02	01/03/01		
Commuter Rail Enhancement Program	RP-PR-000000001	Alt 1	01/10/02	10/13/99	Long Range Plan	Commuter Rail
Maintenance Activities						
Snow and Ice Control	M-1232	Alt 1	01/06/01	N/A	Long Range Plan	Highway
Ditch Cleaning	M-1324					
Operations Activities						
Philadelphia Signal Timing	O-1	Alt 1	01/06/01	N/A	Long Range Plan	Highway

next most recent one. If a project is included in a plan, the name of the plan appears. Other information is available in the list (e.g., the modes or types of transportation addressed).

If one were to select a program such as the STIP, there would be a complete listing of all projects and subprograms in the STIP and summary information, perhaps similar to the summary of program characteristics and impacts shown in Table 16, drawn from the Wisconsin DOT's 1980-86 Six-Year Highway Investment Improvement Program. A more contemporary summary, of course, would have more complete air quality and other measures.

In general, the EIM&DSS would be able to provide a matrix of the impacts of any alternative, scenario, or version of a plan, program, project, and O&M activity in response to a user selecting a report or performing ad hoc queries. A generic format for display of such a matrix is shown in Figure 29. This sample view presents the following:

- The name of the plan, program, project, or operations or maintenance activity;
- Identification number;
- Version/scenario/alternative name;

Table 16. Sample Summary of Alternative Program Characteristics and Impacts

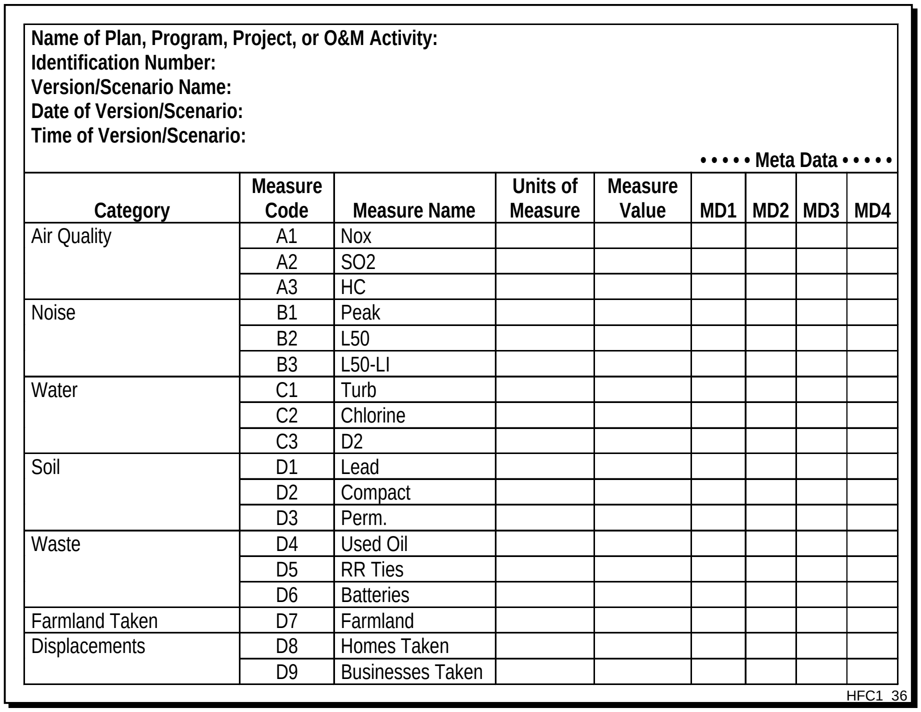
(WISDOT 1980–1985 Six year Highway Improvement Program)

Table S.2
SUMMARY
RRR PROGRAM OPTIONS
LOW AND RECOMMENDED

	Low	Recommended
Program Description (1980-85)		
Total Cost (millions)	$210	$370
Total Miles	1,550	2,153
Cost per Mile (thousands)	$135.0	$153.0
Miles of Work by TYPE		
Resurfacing and Minor Reconditioning	1,095	1,345
Major Reconditioning	318	524
Reconstruction	137	284
Total Number of Projects	544	696
Average Deficiencies Addressed		
Accident Rate	312	322
Accident Occurrences	446	440
Capacity (V/C)	0.55	0.52
Geometrics (% no passing zone)	38	39
Average Daily Traffic	4,308	4,212
Impacts on Transportation Performance (1980-85)		
Total Accidents Reduced per Year	479	811
Miles of Congestion Addressed	77.5	131.0
Social, Economic, and Environmental Impacts (Reconstruction & Major Reconditioning)		
Number of Construction Jobs Generated (person years of work, all projects)	5,550-5,960	8,850-9,480
Income Generated Statewide ($ million, all projects)	$149.9	$226.1
Number of Businesses Displaced	26	44
Improvement in Peak Period Accessibility	466	630
Households Displaced	74	100
Neighborhoods Severed	0	0
Farm Land Required (acres)	1,510	1,946
Farms Severed	38	48
Wetland Encroachment (acres)	146	186
Habitat Required (acres)	570	1,150
Infringements on Endangered Species	0	0
Infringements on Unique Areas (total)	20	22
Historic/Archaeologic Sites	4	6
Other (Parks, Wildlife Refuges, etc.)	16	16
Air Quality (Number of Projects)		
No Change in Carbon Monoxide Concentrations	108	178
Increased Carbon Monoxide Concentrations	4	6
Decreased Carbon Monoxide Concentrations	32	42
Noise (Number of Projects)		
Total Number of Projects	152	226
To Exceed Existing Noise Levels (No. of Projects)	12	12
To Exceed Federal Design Noise Criteria (No. of Projects)	66	90
Energy Consumption (BTU x 10^{12}, all projects)		
Materials and Construction Fuel	2.3-4.9	3.4-8.5
Vehicle Consumption	n.a.	n.a.
Public Acceptability of Improvements (No. of Projects)		
No Controversy	84	120
Low Controversy	54	88
High Controversy	14	18
Number of Projects by WEPA Class (All projects)		
Type I	8	20
Type II	76	157
Type III	422	502
Unclassified	38	17

- Date of version/scenario/alternative;
- Time that version/scenario/alternative was established;
- Impact or performance measures organized by ESCE category;
- The name of each measure;
- A unique code for each measure;
- The units of measurement for each measure;
- The value each measure takes on; and
- An entry for each type of metadata regarding each measure.

Figure 29. Matrix of Impacts of Plan, Program, Project or O&M Activity



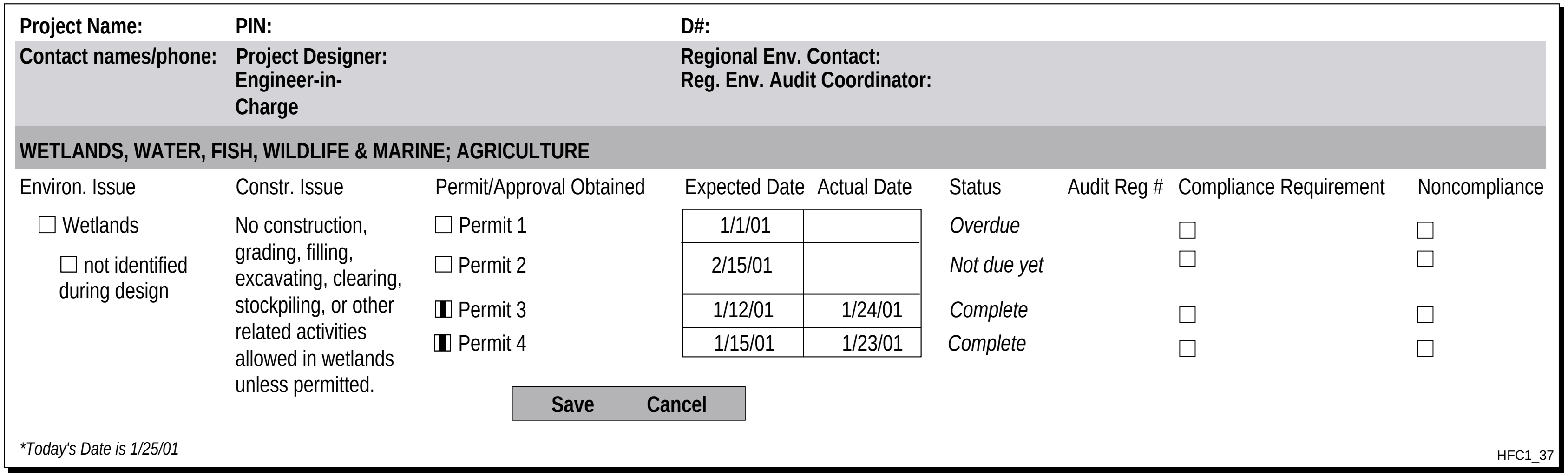
Name of Plan, Program, Project, or O&M Activity:
Identification Number:
Version/Scenario Name:
Date of Version/Scenario:
Time of Version/Scenario:

					••••• Meta Data •••••			
Category	**Measure Code**	**Measure Name**	**Units of Measure**	**Measure Value**	**MD1**	**MD2**	**MD3**	**MD4**
Air Quality	A1	Nox						
	A2	SO2						
	A3	HC						
Noise	B1	Peak						
	B2	L50						
	B3	L50-LI						
Water	C1	Turb						
	C2	Chlorine						
	C3	D2						
Soil	D1	Lead						
	D2	Compact						
	D3	Perm.						
Waste	D4	Used Oil						
	D5	RR Ties						
	D6	Batteries						
Farmland Taken	D7	Farmland						
Displacements	D8	Homes Taken						
	D9	Businesses Taken						

HFC1_36

Figure 30 presents another example of the type of information that would be available if a well-defined enterprise data model were established and implemented. This example is part of a compliance checklist based on one developed by the New York State DOT to ensure that all environmental permits for a project are obtained. The example also illustrates a data entry computer screen that allows a user to enter compliance information and save it. The compliance checklist includes the following information:

Figure 30. Sample Compliance Checklist



Project Name: **PIN:** **D#:**

Contact names/phone: **Project Designer:**
Engineer-in-Charge
Regional Env. Contact:
Reg. Env. Audit Coordinator:

WETLANDS, WATER, FISH, WILDLIFE & MARINE; AGRICULTURE

Environ. Issue	Constr. Issue	Permit/Approval Obtained	Expected Date	Actual Date	Status	Audit Reg #	Compliance Requirement	Noncompliance
☐ Wetlands	No construction, grading, filling, excavating, clearing, stockpiling, or other related activities allowed in wetlands unless permitted.	☐ Permit 1	1/1/01		*Overdue*		☐	☐
☐ not identified during design		☐ Permit 2	2/15/01		*Not due yet*		☐	☐
		◧ Permit 3	1/12/01	1/24/01	*Complete*		☐	☐
		◧ Permit 4	1/15/01	1/23/01	*Complete*		☐	☐

**Today's Date is 1/25/01*

- Project name;
- Project identification number (PIN);
- District number (D#);
- Engineer-in-Charge contact information;
- Regional environmental contact information;
- Regional environmental audit coordinator information;
- Environmental area (e.g., wetlands, water, fish, wildlife, marine, and agriculture);
- Environmental issue;
- Contractor issue;
- Permit approval requirement;
- Expected date of approval;
- Actual date of approval;
- Status;
- Audit requirement number;
- Compliance requirements; and
- Noncompliance information.

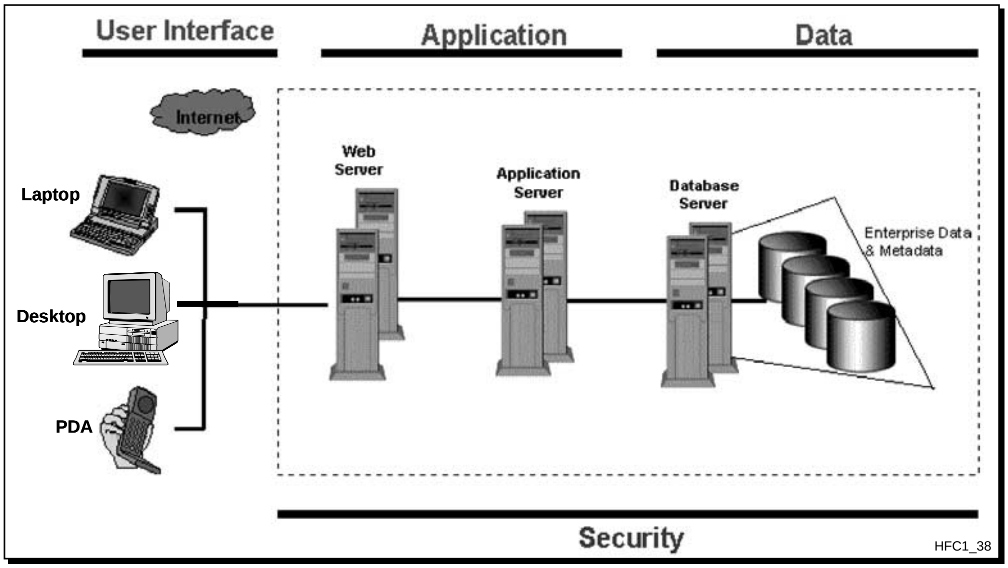
ARCHITECTURE STRATEGIES

The technical architecture for an EIM&DSS that will meet the needs of the DOTs and MPOs in the 21st century needs to be accessible, scalable, and reliable. The underlying system technologies must enable customers and stakeholders to access and integrate data stored in a broad array of formats (e.g., databases, geospatial data, documents, and website information). Figure 31 provides a high-level view of the multi-tiered, web-based EIM&DSS solution.

The EIM&DSS technology architecture is composed of four logical components: User Interface, Application, Data, and Security.

User Interface. The user interface needs to be accessible and straightforward to use to those that understand the business process. The user will need to be able to access the system through all devices

Figure 31. Overview of EIM&DSS Technology Architecture



that have access to the Internet (e.g., desktops, laptops, PDAs, and cell phones). At the user login screen, the application will check the security rules associated with that user, and the interface will be tailored to display the appropriate information to the user's role or use case.

Application. The web server provides connectivity between the user's device and the application server. The software residing on the web server manages connectivity and supports resource management—directly affecting system performance. It is important that the web server software is designed to support the expected number of database connections for current and future needs. In addition, the web server itself needs to be a machine that can serve the anticipated number of users. Examples of web server software include J-Run, Websphere, Tomcat, Apache, and NTIIS.

The application server is where the application itself resides, user processes are executed, and requests from the client software are conducted. The complexity and volume of the type of processes that need to be executed drive the selection of the application software and application server. Examples of application software include Java, C++, ASP, and Visual Basic.

Data. The database server houses the database software and the actual data. Database software needs to be robust enough to handle the volume and type of data to be collected. Examples of database software include Oracle, SQL Server, Sybase, and Informix.

Security. Security is a very important aspect of the technical architecture. Security is enforced at many levels of the enterprise architecture, including the network, the application, and the database. Security must be carefully coordinated and implemented in order to protect the organization's investment while meeting the demands of information accessibility.

Ultimately, users expect business processes that communicate and share data that has the same meaning across the organization. The key to success is compatibility and scalability both within and across enterprises. Various high-level business process requirements must be supported by an EIM&DSS. These requirements are the result of a synthesis of the literature review, team knowledge, survey input, and best practices documents submitted in response to e-mail query. These requirements are as follows:

- Is accessible via Internet/Intranet;
- Is ODBC compatible;
- Provides information access security levels;
- Protects copyrighted and proprietary data/files;
- Supports data sharing capabilities, such as XML formatting;
- Has the ability to validate data on entry;
- Provides workflow management capabilities;
- Supports wireless technology capabilities;
- Complies with accessibility standards; and
- Uses non-proprietary/portable software code, such as Java,wherever possible.

TECHNICAL ARCHITECTURE LOOK AT ELEMENTS OF OBJECT MODEL FOR DISTRIBUTED SYSTEMS

Another perspective regarding the EIM&DSS is an object model for distributed systems. As discussed below, it is highly likely that the EIM&DSS will ultimately function in a technical environment of distributed computing. Software functionality will be provided through software objects that are accessible from various platforms, including desktop and sensors. Both public agencies and private firms will function as application service providers. Part of the task in understanding the functionality and future technical architecture for the EIM&DSS ought to be to fully absorb the object model described in this Handbook, which is detailed under Step 5, "Assess the Evolution of Technology."

STUDY ROLE OF CONTENT MANAGEMENT

Content management is critical to the successful implementation, ongoing use, and evolution of the EIM&DSS. Essential elements of content management are as follows:

CAUTION!

- **Assessment of Net Value of Data.** The value of data needs to exceed the cost of collecting, storing, and maintaining it. Rigorous procedures are required to ensure EIM&DSS data is worth collecting. It is not uncommon for agencies to underestimate the lifecycle costs of data required for a management system. Consequently many management systems cease to be used or fall far short of their potential because there was an unrealistic expectation regarding the ease and cost of gathering the data the system required.

- **Responsibilities for Data Collection and Maintenance.** A key aspect of content management is assigning responsibility for gathering, storing, and updating each type of data and corresponding metadata (data describing data). Responsibilities can be assigned to internal staff or to consultants or contractors. Many agencies that handle content management well publish the name of the responsible party, which has the effect of increasing the sense of responsibility of each person carrying out data management functions.

- **Data Quality Assurance.** Another critical element of content management is developing and applying procedures to ensure the quality of the data. Users should be confident that the data is accurate enough for the purpose intended. Data that purports to represent certain conditions or facts should represent them. If data is expected to pertain to a particular time period, then the correspondence should hold. If there is a need to summarize data by organizational unit, subdivision, or government jurisdiction, then the data should allow the breakdown. If the data is intended to have scientific statistical meaning, then the statistical accuracy and confidence needs to be known.

- **Metadata.** As mentioned earlier, content management must include the development, storage, and sharing of metadata, which describes the nature, coverage, time period, source, and other information regarding each type of data. Metadata concerning GIS data should include the scale and projection of the digital maps.

- **Extensible Markup Language (XML).** In the future, data sharing will require the exchange of metadata to facilitate processing and communicating of transportation and environmental data over the Internet. Communities of individuals wishing to share information will establish commonly recognized data that conforms to the communication standard for XML.

STUDY ROLE OF WORKFLOW MANAGEMENT

During the 1990s organizations in both the public and private sector became increasingly engaged in business process engineering. Typically this involves documenting existing business processes and then detailing desired business processes. Software tools were often used to establish existing and desired business processes. Out of this background have developed sophisticated software tools and procedures for managing workflow. For example, one major corporation has integrated workflow management into software for internet business-to-business commodity exchanges. Another company has integrated workflow management in a widely used maintenance management system.

Incorporating workflow management into the EIM&DSS is crucial in order to increase the efficiency of transportation and environmental management and to streamline delivery of transportation products and services that customers demand.

Many firms now offer commercial software that one can use to diagram a desired business process, assign specific responsibilities associated with a particular step in the business process, and manage the processing of data as one proceeds from one step to another. Workflow management systems that permit electronic approvals can help both streamline and speed up a business process.

LOOK AT HOW TO ACCESS BEST MANAGEMENT PRACTICES

The EIM&DSS needs to provide information on best management practices concerning both transportation and environmental issues. Indeed the American Association of State Highway and Transportation Officials (AASHTO) has identified the provision of best management practices over its website as the number one priority for web services. Best management practices can be provided in many ways, including the following:

- An on-line repository of BMPs organized by topic;
- BMPs derived from benchmarking (In other words, conducting comparative studies of performance of different organizational units or organizations, identifying the best performers, and then identifying the practices associated with the best performers. These practices are best practices);
- A learning management system focused on delivery of training regarding best practices;
- An on-line store that provides material on best practices; and
- Access to experts who can provide advice on best management practices.

Figure 32 presents a screen for a prototype website dealing with BMPs.

Figure 32. Prototype Home Page for Best Practices

BEST MANAGEMENT PRACTICES WEBSITE
(BMPs)

- BMPs – Environmental Areas
- BMPs – Transportation Activities
- BMPs – Levels of Decision Making
- Benchmarking
- Training
- Experts
- Guidelines, Policies, Specs, Standards
- Other Source Material

STEP 4. ASSESS EXISTING CAPABILITIES

This handbook provides a tool that agency staff can use to assess the existing capabilities of the agency. The tool is based primarily on the "upside-down layer cake" shown in Figure 33. Agency staff need to assess the capabilities of the existing organization beginning with the bottom layer and then work to the top. **At the beginning of each implementation phase or significant incremental step, agency staff need to reassess how far the agency has progressed toward the top, and what layer(s) the agency will implement next. The ability to implement most layers is dependent upon implementation of the previous (lower level) layers, but some layers can be implemented independent of many others, for example a web portal for accessing information on best management practices.**

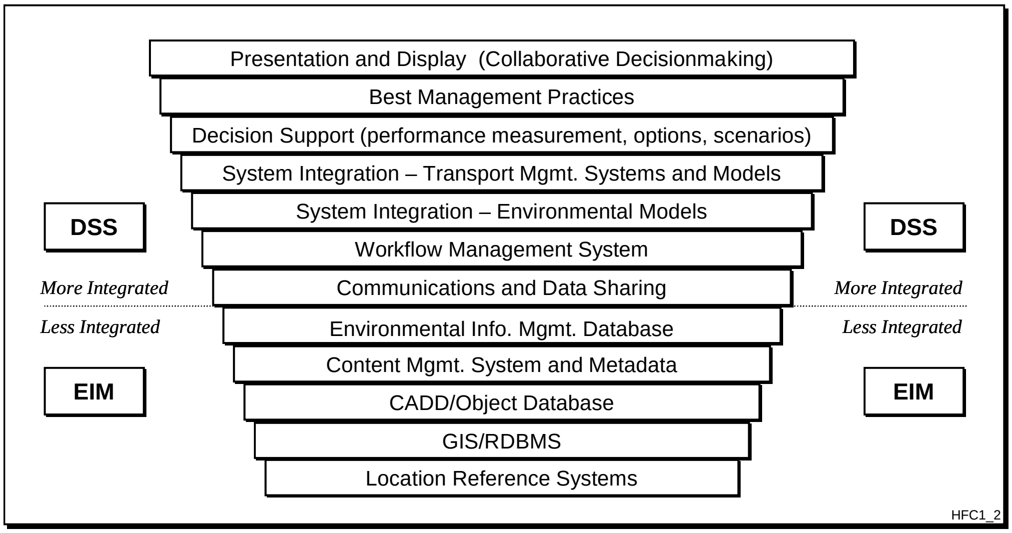
Elements below the dotted line constitute the EIM system while elements above the line constitute the DSS. Elements below the dotted line are assumed to be implemented in an environment that lacks significant data sharing and systems integration. Data sharing, systems integration, and collaborative decision making increase from the dotted line up.

DECISION TREE

The agency should work through each step of the decision tree in Figure 34 to determine how far the agency has evolved and what steps to take next. The decision tree assumes an EIM system, composed of the following elements, is the minimum that the agency should have or implement during the first phase, in order to have the most basic environmental information management capabilities:

- Location reference systems—
  - Linear reference system (LRS), and
  - Coordinate reference system (CRS);
- GIS; and
- Well-defined relational database tables for managing environmental information that is primarily intended to organize and facilitate storing and retrieving data.

Figure 33. Layers of EIM&DSS



Although this minimal EIM does not include a decision support layer, the database should be designed with decision support needs in mind, because decision support ultimately determines the data requirements of the EIM&DSS vision the agency is striving to achieve. Indeed, the agency may wish to implement the decision support layer along with the basic EIM.

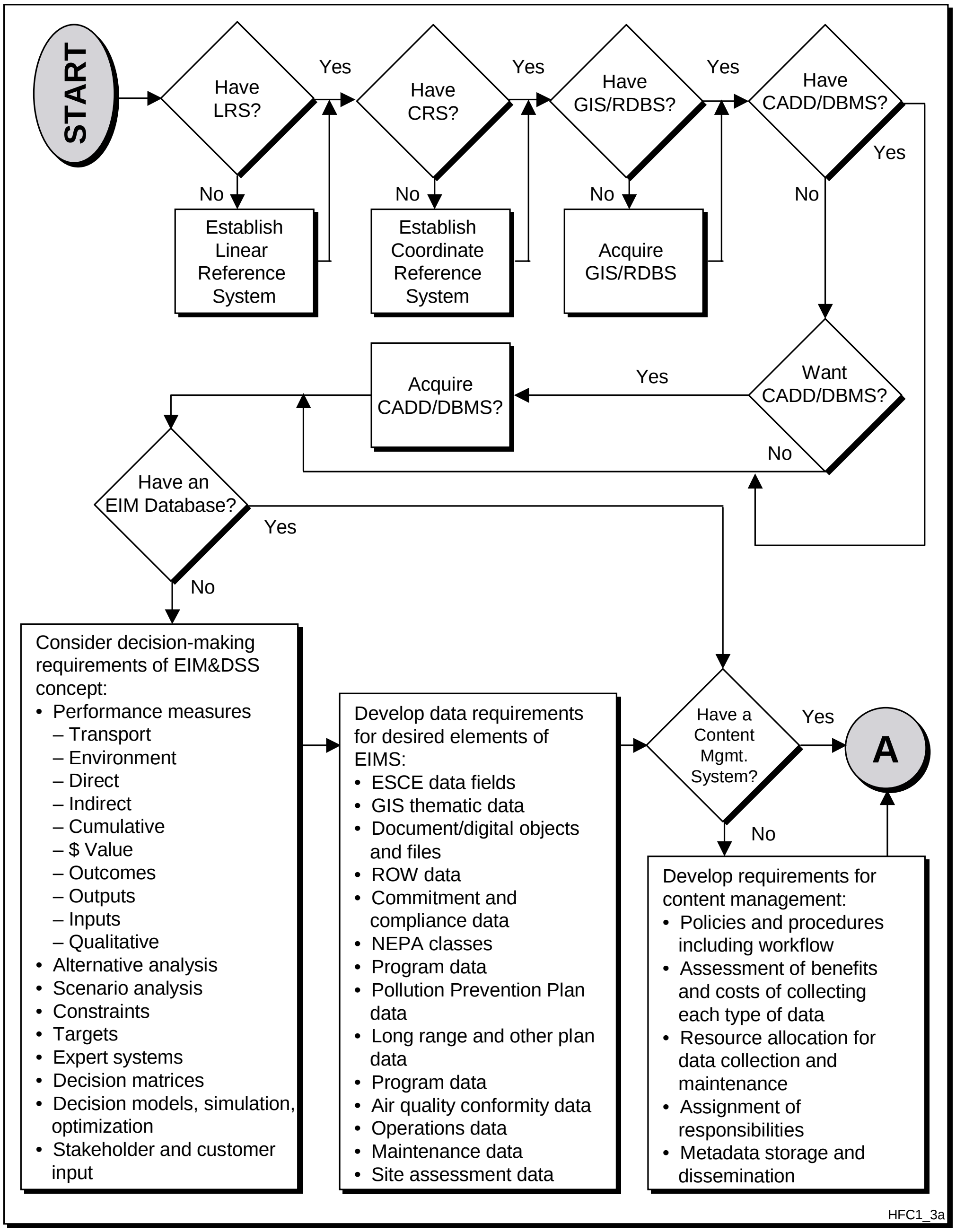
For all of the remaining elements of the EIM&DSS shown in Figure 33, the decision tree in Figure 34 asks two questions:

1. Does the agency have the element?
2. Does the agency want the element?

Any element that the agency does not have can either be implemented in the current phase or deferred to the next phase, depending on whether the agency wants it or does not want it in the current phase. In the decision tree in Figure 34, the two questions above are asked of each of the following elements:

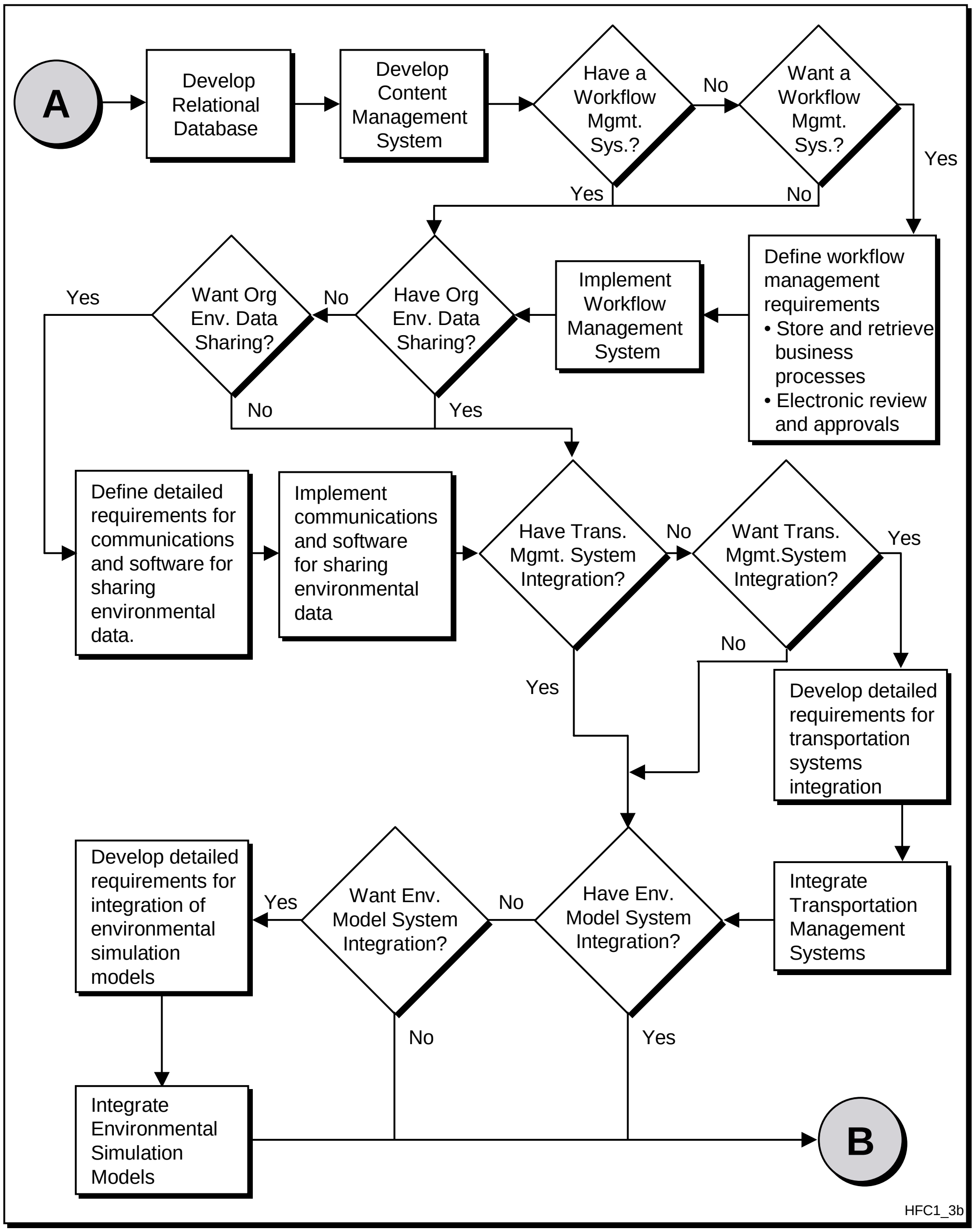
- CADD/object database;
- Workflow management system;
- Communications and data sharing software and infrastructure;
- Integration of environmental simulation models;

Figure 34. Self-Assessment Decision Tree for Evaluating Existing and Desired Elements of EIM&DSS



- ♦ Integration of transportation management systems and models;
- ♦ Decision support structure, including complete and detailed definition of transportation and environmental performance measures, accommodation of alternatives and scenarios, and incorporation of decision models, simulations, and optimization;

Figure 34 (Continued). Self-Assessment Decision Tree for Evaluating Existing and Desired Elements of EIM&DSS

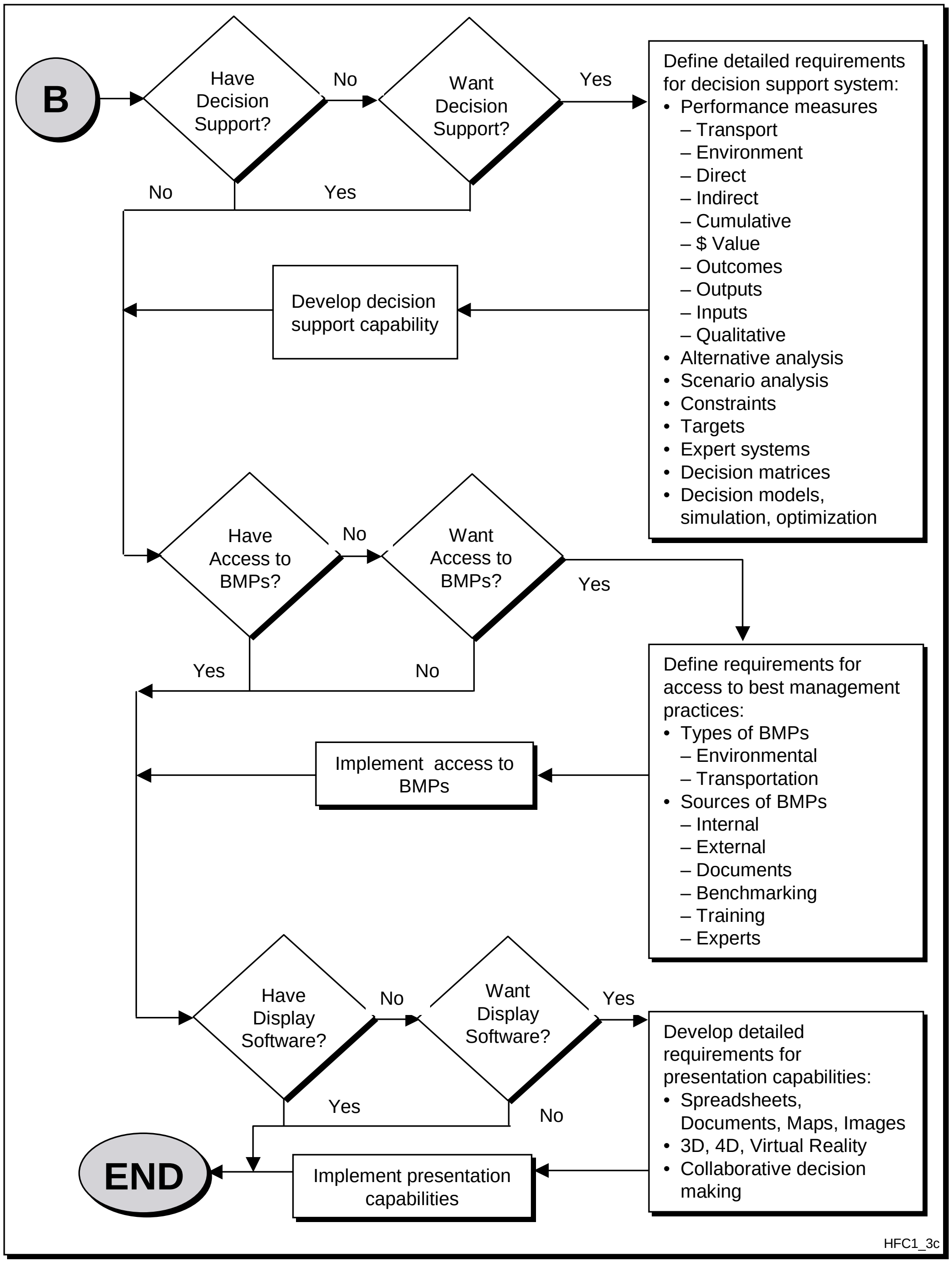


- ♦ Access to information on BMPs; and
- ♦ Presentation and display software for collaborative decision making (e.g., spreadsheets, images, video, 3D, 4D, and virtual reality).

OBSERVATIONS

Examination of Figure 34 reveals the following:

Figure 34 (Continued). Self-Assessment Decision Tree for Evaluating Existing and Desired Elements of EIM&DSS



1. Location reference systems are fundamental to a practical EIM&DSS that will serve the needs of all levels of decision making and various modes of transportation. **Agency staff need to make sure the agency has adopted a well-defined LRS. In addition staff must define a standard CRS with a known geodetic datum (projection) if they intend that a GIS be an integral part of the EIM&DSS.** Many agencies use digital

orthophotos to develop base maps that have a high accuracy (e.g., within 30 feet of ground truth). If the agency plans to use environmental and transportation information that in the future must be more accurate, the agency will need to establish anchor points representing "ground truth" that tie the end points of linear segments or other point locations (e.g., survey benchmarks) to points on a GIS digital base map; the accuracy of these anchors can be established using GPS receivers and differential processing and ought to be known in terms of both precision and a statistical confidence interval. Ideally, the accuracy should be very high, [e.g., within a few inches or centimeters with 95% confidence if static measurements are taken and within a few feet if using land-based kinematic GPS (e.g., GPS mounted on a van moving 50 mph)] and differential processing. Agencies often develop anchor points when establishing a digital centerline for highways. In addition, staff need to be able make the following conversions: (1) between the base LRS that has been tied to ground truth and the base CRS that has been tied to ground truth; (2) among all key LRS that the agency uses; and (3) among all key CRS that the agency uses. This will ensure that staff can convert any LRS to any coordinate system in a manner tied to ground truth. The agency also may want to have an Address Referencing System (ARS) (e.g., street business and residence address numbers that can be tied to the LRS).

2. A CADD system, including a relational and object database, can be implemented as a distinct part of the EIM&DSS. **However, if the agency has an integrated GIS, CADD and relational-object database, then the agency has the hardware and software capability to satisfy most of the presentation requirements of the EIM&DSS concept, assuming the GIS/CADD/RDBMS is linked to the Internet.**

3. Although a workflow management system is not considered an element of the most basic system, it is an essential part of the full EIM&DSS concept in order to support efficient business processes for data processing, analysis, and streamlining of transportation and environmental decision making.

4. System integration that allows sharing of information and analysis is considered a separate implementation phase. Sharing of information can be achieved in many ways, including a centralized data warehouse or distributed processing. Web-enabled data sharing is assumed.

5. The ability to exercise simulation models, optimization procedures, priority ranking algorithms, expert systems, and so forth is another distinct element of the EIM&DSS concept and generates decision inputs as a result of running scenarios and storing them in a database.

6. Ideally, the decision support layer should be developed at the very beginning of the first implementation phase as a part of defining system and analytic requirements. Most state DOTs understand the level of detail and the basic environmental, social, cultural, and economic information required to prepare an EIS involving highway and transit options. However, few agencies know what types of transportation and environmental data and the appropriate level of detail needed for other modes or for planning, programming, operations, and maintenance. Very few, if any agencies, have defined a full set of transportation and environmental performance measures—including outcomes, outputs, and inputs—that cut across all the key mobility, accessibility, durability, ecological, social, economic, and cultural issues. It takes a long process of consensus building to reach agreement that a performance measure should be used.

7. Just as it will be necessary to develop the EIM&DSS incrementally, it will be necessary to take incremental steps to develop the decision support layer, including the ability to store and retrieve values for performance measures for each alternative or scenario being analyzed for a particular decision. It is advisable to begin with transportation and environmental factors that are most commonly addressed in highway EISs and build from there.

STEP 5. ASSESS THE EVOLUTION OF TECHNOLOGY

Transportation agencies making major investments in information management systems and decision support systems, such as bridge or pavement management systems, expect such systems to have a useful life of at least 10 years. It is reasonable to assume that transportation agencies will have a similar expectation regarding the life of the core features of an EIM&DSS.

To achieve a software life of 10 years is challenging because of rapid technological change and continually evolving information and analytic needs. Many types of technology become outdated within 12 to 24 months. A critical part of implementation planning for the EIM&DSS is to ensure that development focuses on those parts of the EIM&DSS that will be required, regardless of how technology evolves, and to take advantage of existing and emerging technology in order to enhance the core capabilities as much as possible.

M METHOD Rigorous

In regard to keeping up with technology, each transportation agency will need to perform a technology assessment associated with each incremental step it takes toward full implementation of the EIM&DSS concept. Elements of the technology assessment are as follows:

- Identify the technology that is most appropriate to the implementation step and that will enable or enhance the functionality to be provided;
- Assess the ability of the organization to satisfy the technology requirements, given the organization’s existing technology and capabilities;
- Identify the gap between the requirements and current agency technology resources and capabilities; and
- Determine the optimal timing and amount of expenditures to close the gap between existing and required technological capabilities. (The optimal expenditure for a needed technology is determined by minimizing the discounted present value of the sum of (1) the avoided costs of premature obsolescence and (2) the costs of acquiring, operating, and maintaining the technology.)

What specific technology should be a prime consideration in implementing an EIM&DSS? The concept for the EIM&DSS has numerous technological facets, including hardware, software, telecommunications, and data acquisition technology. It is not possible to address every type of technology that might be considered. Instead, this section focuses on the following two groups of technology:

- Technology that can improve consideration of environmental concerns in transportation decisions (such technology was identified and evaluated under NCHRP Project 25-22) and
- Technology that will lead to seamless data sharing and on-line analytic services in a distributed computing environment that will be characteristic of the Internet in the next 5 to 10 years.

EXAMINE TECHNOLOGY EVALUATED UNDER NCHRP PROJECT 25-22

NCHRP Project 25-22 identified and evaluated a broad range of technology potentially useful for environmentally sound transportation decision making. The technology determined to be most useful was organized into four broad areas as follows:

1. Geospatial and database technologies,
2. Remote sensing technologies,
3. Transportation impact modeling technologies, and
4. Visualization/simulation technologies.

Each technology was evaluated according to its applicability to different geographic scales (e.g., site, facility, corridor, local area, regional, statewide, and multi-state), different stages of a project lifecycle (i.e., planning through operations and maintenance), the likelihood of achieving various user benefits (e.g., cost and schedule, resource management, and user-friendliness of data), and the likelihood of technology adoption and integration in light of agency experience with the technology, leadership interest, staff willingness to apply the technology, availability of the technology, and the dollar costs of adoption.

Details of the technology assessment are provided on CRP-CD-ROM 14, *Technologies to Improve Consideration of Environmental Concerns in Transportation Decisions* (contact NCHRP regarding

purchase and availability). The specific technologies described and evaluated in the CD-ROM are as follows:

- General Database Technologies—
    - Electronic field data,
    - Collaborative planning and design,
    - Electronic reporting, and
    - Facility information management systems;
- Remote Sensing Technologies—
    - Terrestrial light detection and ranging system,
    - Airborne light detection and ranging system,
    - Digital aerial photography and photogrammetry,
    - Radar imaging and mapping,
    - Multi-spectral and hyper-spectral satellite imaging,
    - Multi-spectral and hyper-spectral airborne imaging,
    - Ground-penetrating radar, and
    - Digital photolog;
- Transportation Impact Modeling Technologies—
    - Gap analysis,
    - Integrated models, and
    - Expert systems;
- Decision Science Technologies—
    - Multi-attribute utility analysis,
    - Prioritization,
    - Decision analysis, and
    - Optimization; and
- Visualization/Simulation Technologies—

- 3D and
- 4D.

Three tables from the CD-ROM summarize the assessment. Table 17 summarizes the phase of the project delivery cycle to which each technology is applicable. For example, electronic field data collection involving geospatial database technologies (e.g., GPS receivers wedded to digital maps) are useful for describing existing conditions and identifying and framing problems associated with jurisdictional planning, geographic planning, and project development. In addition field data collection technology is useful for preliminary design, ROW acquisition, construction, operations, and maintenance. In contrast, 3D and 4D visualization and simulation technologies were deemed as having value for every part of the project delivery phase and every aspect of environmental decision making studied under NCHRP Project 25-22.

Table 18 summarizes the geographic scale to which each technology is applicable. Technology that has applicability to every geographic scale of analysis includes most types of geospatial database technology, most types of transportation impact modeling technology, and visualization and simulation technology. Data collection technology, whether for field data collection or involving remote sensing, tends to be more specific to particular scales of geographic analysis.

Table 19 summarizes how ready each technology is in terms of different technology benefits relative to the extent the technology is currently used, the support for the technology, and the costs and challenges of adoption and integration. **One pattern that emerges from this table is that a technology is not as ready for implementation as another technology, if the first technology requires substantial agency commitment, familiarity, and systems integration.** For example, because agencies currently make extensive use of digital aerial photography and photogrammetry, there is fairly strong leadership interest and staff willingness to apply the technology. This technology already has many different kinds of demonstrated benefits ranging from improved understanding of tradeoffs (e.g., avoidance versus mitigation) to improved probability of permit approval. Other technologies, such as 4D visualization and simulation, while potentially yielding a wide variety of benefits, is not currently used very much, is not widely available, lacks staff willingness to apply the technology, and has various significant dollar costs associated with it.

Table 17. Phases of Project Lifecycle to Which Technology is Applicable

	Technology and Technology Categories	Geospatial Database Technologies				Remote Sensing Technologies								Transportation Impact Modeling Technologies			Decision Science Technologies				Visualization/ Simulation Technologies	
		Electronic Field Data Collection	Collaborative Planning & Design	Electronic Reporting	Facility Information Management Systems	Terrestrial Lidar	Airborne Lidar	Digital Aerial Photography & Photogammetry	Radar Imaging & Mapping	Multi-spectral & Hyper-spectral Satellite Imaging	Multi-spectral & Hyper-spectral Airborne Imaging	Ground-penetrating Radar	Digital Photolog	Gap Analysis	Integrated Models	Expert Systems	MUA	Prioritization	Decision Analysis	Optimization	3D	4D
PROJECT DELIVERY PHASE	**Jurisdictional Planning**																					
	Description of existing conditions	X	X		X					X				X	X	X				X	X	X
	Problem identification and framing	X	X		X					X				X	X	X	X	X		X	X	X
	Alternative identification and refinement		X		X					X				X	X	X	X	X		X	X	X
	Alternative evaluation		X		X					X				X	X	X	X	X	X	X	X	X
	Alternative selection		X		X					X				X	X	X	X	X	X	X	X	X
	Public involvement		X	X	X					X				X	X	X	X	X			X	X
	Process documentation		X	X	X					X				X	X	X	X	X	X	X	X	X
	Geographic Planning																					
	Description of existing conditions	X	X		X		X	X	X	X	X			X	X	X				X	X	X
	Problem identification and framing	X	X		X		X	X	X	X	X			X	X	X	X	X		X	X	X
	Alternative identification and refinement		X		X			X	X	X	X			X	X	X	X	X		X	X	X
	Alternative evaluation		X		X		X	X	X	X	X			X	X	X	X	X	X	X	X	X
	Alternative selection		X		X		X	X	X	X	X			X	X	X	X	X	X	X	X	X
	Public involvement		X	X	X		X	X	X	X	X			X	X	X	X	X			X	X
	Process documentation		X	X	X			X	X	X	X			X	X	X	X	X	X	X	X	X
	Project Development																					
	Description of existing conditions	X	X		X		X	X	X	X	X	X	X	X	X	X				X	X	X
	Problem identification and framing	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
	Alternative identification and refinement		X		X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
	Alternative evaluation		X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Alternative selection		X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Public involvement		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X			X	X
	Process documentation		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Preliminary Design	X	X	X	X	X	X	X	X		X	X	X	X		X			X	X	X	X
	Final Design		X		X	X	X	X	X		X	X	X						X	X	X	X
	Permitting				X	X	X	X	X		X		X	X		X	X	X	X		X	X
	ROW Acquisition and Construction	X			X	X		X	X				X	X		X	X	X	X	X	X	X
	Operation and Maintenance	X			X	X	X	X	X				X	X		X	X	X	X		X	X

Table 18. Geographic Scale to Which Technology is Applicable

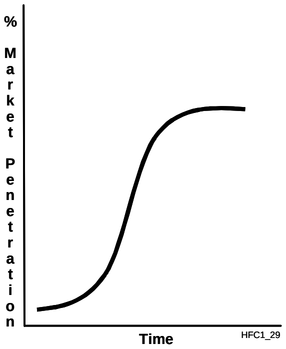
	Technology and Technology Categories	Geospatial Database Technologies				Remote Sensing Technologies								Transportation Impact Modeling Technologies			Decision Science Technologies				Visualization/ Simulation Technologies	
		Electronic Field Data Collection	Collaborative Planning & Design	Electronic Reporting	Facility Information Management Systems	Terrestrial Lidar	Airborne Lidar	Digital Aerial Photography & Photogammetry	Radar Imaging & Mapping	Multi-spectral & Hyper-spectral Satellite Imaging	Multi-spectral & Hyper-spectral Airborne Imaging	Ground-penetrating Radar	Digital Photolog	Gap Analysis	Integrated Models	Expert Systems	MUA	Prioritization	Decision Analysis	Optimization	3D	4D
GEOGRAPHIC SCALE	Multi-state		X	X	X					X				X		X	X	X	X	X	X	X
	Statewide		X	X	X					X			X	X		X	X	X	X	X	X	X
	Regional (multi-county)		X	X	X			X		X			X	X	X	X	X	X	X	X	X	X
	Local area (city/county)	X	X	X	X		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
	Corridor/ Watershed/Airshed (subcounty)	X	X	X	X		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
	Facility (linear segment)	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Site (interchange, transit center)	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X	X	X	X

Table 19. Ripeness of Technology in Terms of Benefits

		Technology and Technology Categories	Geospatial and Database Technologies				Remote Sensing Technologies						Transportation Impact Modeling Technologies			Decision Science Technologies				Visualization/Simulation Technologies	
			Electronic Field Data Collection	Collaborative Planning & Design	Document & Process Management	Facility Information Management Systems	Terrestrial Lidar	Airborne Lidar	Digital Aerial Photography & Photogammetry	Radar Imaging & Mapping	Multi-spectral & Hyper-spectral Airborne Imaging	Ground-penetrating Radar	Gap Analysis	Integrated Models	Expert Systems	MUA	Prioritization	Decision Analysis	Optimization	3D	4D
Technology Benefits	Cost and Schedule	Reduction of work duplication	□	▨	■	□	■	▨	▨	▨	▨	▨	▨	▨	▨	□	□	▨	▨	□	□
		Early identification of fatal flaws/litigation potential	▨	□	■	□	■	▨	□	▨	□	□	□	▨	▨	□	□	□	□	□	□
		Differential of cost from current technology	▨	■	■	■	■	▨	▨	▨	▨	■	□	▨	□	■	■	▨	▨	▨	□
		Reduction in uncertainty of costs	▨	▨	■	■	■	▨	▨	▨	▨	□	▨	▨	■	▨	▨	□	▨	□	□
		Time savings	□	□	■	□	■	□	□	▨	□	□	□	▨	□	▨	▨	□	□	□	□
	Resources Management	Identification of resources	▨	▨	■	▨	■	▨	□	▨	□	▨	□	■	□	■	□	■	■	▨	□
		Improving understanding of tradeoffs (avoidance vs. mitigation)	▨	□	□	▨	□	▨	□	■	□	□	□	□	□	□	□	▨	▨	□	□
		Improving understanding of potential impacts	▨	□	□	▨	▨	▨	□	■	□	□	□	□	□	□	▨	■	□	□	□
		Identification of mitigation strategies	▨	▨	■	■	■	▨	□	▨	□	■	▨	▨	▨	■	▨	▨	▨	▨	□
	User-Friendliness of Data	Improved availability of understandable information	▨	□	□	□	□	▨	□	▨	▨	□	□	□	□	□	□	□	■	□	□
		Potential for engagement of stakeholders	▨	□	□	□	■	□	□	▨	□	□	□	▨	▨	□	□	▨	▨	□	□
		Ease of use of information	▨	□	□	□	■	■	▨	■	■	▨	□	▨	▨	□	□	▨	■	▨	▨
		Technology fosters multidiscipline interaction or collaboration	▨	□	▨	□	■	▨	□	■	▨	▨	□	□	□	□	□	□	■	□	□
		Improved probability of permit approval	▨	▨	▨	▨	■	▨	□	▨	□	■	▨	▨	■	▨	▨	■	▨	□	□
Technology Integration		Extent of current application	■	■	□	■	■	▨	□	▨	▨	▨	▨	▨	■	▨	▨	■	■	■	■
		Leadership interest	▨	▨	▨	■	▨	▨	□	■	□	▨	▨	▨	■	▨	▨	■	■	▨	▨
		Staff willingness to apply technology	□	▨	▨	■	▨	▨	□	▨	□	□	▨	▨	▨	▨	▨	▨	■	▨	■
		Number of process steps in which technology may be applied	■	□	■	□	■	▨	□	▨	▨	■	□	□	□	□	□	▨	■	□	□
		Capital costs of providing technology (hardware, software, equipment acquisition)	▨	▨	□	■	□	□	▨	□	▨	□	▨	□	■	□	□	□	▨	▨	■
		Cost of preparing/training staff	■	■	▨	■	□	□	■	■	■	▨	▨	▨	■	□	□	▨	▨	■	■
		Technology application transaction costs (intangible costs e.g., learning curves)	▨	■	▨	■	▨	▨	▨	■	■	▨	▨	▨	■	□	□	▨	▨	▨	■
		Availability for application of technology (is it readily available)	□	▨	□	■	■	■	▨	■	▨	■	□	□	■	□	□	▨	▨	▨	■
		Maintenance costs of providing technology	■	▨	□	■	▨	▨	▨	▨	▨	▨	▨	▨	▨	□	□	▨	▨	▨	■

□ Best condition ▨ Moderate condition ■ Worst condition

Of course, staff familiarity and inclination to use a technology will change over time as the technology matures, the cost declines, and industry experience becomes more widespread. In general, one can expect that technology diffusion will follow the typical S-shaped pattern illustrated in the figure in the sidebar. The first phase involves early adopters; the second phase involves a period of rapid proliferation of the technology; and the third stage involves a sharp leveling off of growth, often reflecting the emergence of a competing technology or of market saturation.



TECHNOLOGY FOR ACCESSING DATA AND APPLICATIONS IN THE INTERNET ENVIRONMENT

The single most important computing and communications requirement for the EIM&DSS is the ability of users to be able to access relevant information and analytic capabilities in order to make better transportation and environmental decisions. Today, data and applications are in many different forms, databases, and systems that generally are not linked together. Different agencies have had different degrees of success in enabling users to access data and analytic capabilities. Today, nearly every state DOT has a GIS and a CADD system linked to one another and to designers, project planners, and engineers both in the agency and in design firms. However, only a handful of state agencies have developed integrated roadway management systems that store highway information in a centralized database that is accessed by pavement, bridge, and maintenance management systems. Other agencies have embarked on developing an enterprise database management system to house both transportation and environmental data. Many of these approaches have a distinctly centralized flavor to them, but there is little doubt that during the next 15 to 20 years computing and communications will occur in a highly distributed environment that supports seamless access to data and applications located anywhere on the Internet.

Transportation agencies contemplating implementing an EIM&DSS need to fully comprehend the evolution toward distributed computing and the role of existing and emerging technology. Regardless of how far along an agency has evolved toward systems integration and data sharing, decisions regarding implementation of specific parts of the EIM&DSS will occur against a backdrop of innovations and commercial software development that will allow widely dispersed data and applications to be nearly instantly delivered to a user on virtually any platform. Equally important, any significant part of the EIM&DSS that an agency

decides to implement will need to function effectively for many years into the future as distributed computing becomes ubiquitous. Understanding the history of computing in the DOTs helps to put this trend into perspective and will help transportation agencies make appropriate choices regarding the extent to which they should embrace technology for distributed computing each step of the way toward full realization of the EIM&DSS concept.

History of Computing in DOTs

Transportation agencies, such as state DOTs, had compelling reasons over the past four decades to lean toward centralized approaches to computing. One reason has been that many DOTs manage Division of Motor Vehicle functions—vehicle titling, registration, and driver licensing—that require stringent security and favor centralized computing resources, especially a centralized database management system. Through the 1960s, large mainframes housed these systems. It was natural for the automation service bureaus of DOTs to use their centralized resources—both computers and staff—to provide other centralized services in support of planning, financial management, design, construction, maintenance, and operations. Even when minicomputers began to replace many mainframes, a centralized computing environment remained.

The advent of the personal computer resulted in a substantial paradigm shift that put powerful computing resources on the desktop of each person. In a compromise, increasing numbers of individuals were provided with personal productivity and communication tools (e.g., word processing, spreadsheets, presentations software, and e-mail) on PCs and MACs and these were connected to mainframes in a two-tier architecture that mimicked the mainframe terminals that preceded them.

Over time, various planning, programming, project development, operations, and maintenance functions have required their own computer applications, systems, and software. These have taken many different forms, including stand-alone applications such as spreadsheets and BASIC computer programs. Among the most common are applications offered in a client-server architecture, where an application and a relational database have been housed in a box containing one or more microprocessors that are linked via a local area network or a wider area communications network to the desktop computers of users. The number of clients may range from a few to hundreds, or even approaching a thousand.

In order to realize the efficiencies that can be achieved by separation of data management from business logic, three-tier architectures became common where the database is on one server, the application on another, and the clients are on a third. But this evolution did little to overcome stovepipe applications such as pavement, bridge, and maintenance management systems that do not communicate with one another.

During this time, an increasing proportion of software changed from being highly procedural (such as Cobol, Fortran, Pascal, and BASIC) to being object-oriented (such as C++ and Java). More and more, computer applications have involved computer objects that have methods and attributes and have promoted modularization and reuse to an unprecedented degree. By the late 1990s, widely used commercial office suites supported object linking and embedding. Even though the typical user was not familiar with software objects, they depended on them daily in their computing tasks.

With the emergence of the Internet, particularly the World Wide Web, web applications have become increasingly important. Web applications have ushered in n-tier architectures, which refer to more than three levels of processing. One example of an n-tier architecture found in the commercial environment involves a database server, an application server, a web server, a message queuing server, and client servers. In order to provide for large numbers of users, it is not uncommon for 24, 64, or even 264 and more microprocessors to be involved in Internet portals serving large numbers of users.

Frameworks for Distributed Computing

Agencies assessing the next step to take in implementing an EIM&DSS should consider how the EIM&DSS might fit into various frameworks for distributed computing and whether agencies want to use one of the following frameworks:

- Microsoft.Net,
- Sun Microsystems J2EE,
- Oracle’s, and
- IBM’s.

These and other frameworks potentially allow a user on virtually any platform to access information and applications located anywhere on the Internet provided the user has access privileges consistent with the security surrounding the use of the data and applications. These frameworks will allow both free access and pay-for-use. Some of the elements of these systems also involve source code developed in a manner consistent with the "open source" movement; code is posted on the Internet, which allows developers throughout the world to examine and use the code and offer improvements.

Widely used distributed frameworks accommodate a substantial degree of interoperability across languages or platforms. The distributed computing framework for Java 2 Enterprise Edition (J2EE) is built on the Java programming language, which can run on any platform that hosts a Java Virtual Machine. Microsoft.Net relies on the standard industry markup language XML and offers compatibility across a number of very different but proprietary versions of languages that include industry or de facto standards, such as SOAP and Visual Basic.

Both the J2EE and the Microsoft.Net are likely to be the most pervasive software environments for distributed computing for the first two decades of the twenty-first century and, therefore, are worth describing briefly.

Figure 35 presents the J2EE architecture composed of four tiers: client, web, business, and EIS (Alui et al., 2001). The J2EE architecture includes the following elements:

- Java 2 Software Development Kit (SDK) (Standard Edition);
- Java 2 Runtime Environment, Standard Edition;
- Java application components;
- Applet components;
- Servelets and Java Server Pages (JSPs);
- Enterprise Java Beans (EJB) components;
- Hypertext Transport Protocol (HTTP);
- HTTP over Secure Socket Layer;
- Java Database Connectivity (JDBC);
- Java Activation Framework;
- Remote Method Invocation/Internet-Orb Protocol (RMI-IIOP);
- Java Interface Definition Language;
- Java Transaction Application Program Interface (API);
- Java Message Server (JMS); and
- Java Naming and Directory Interface.

Figure 35. J2EE Architecture

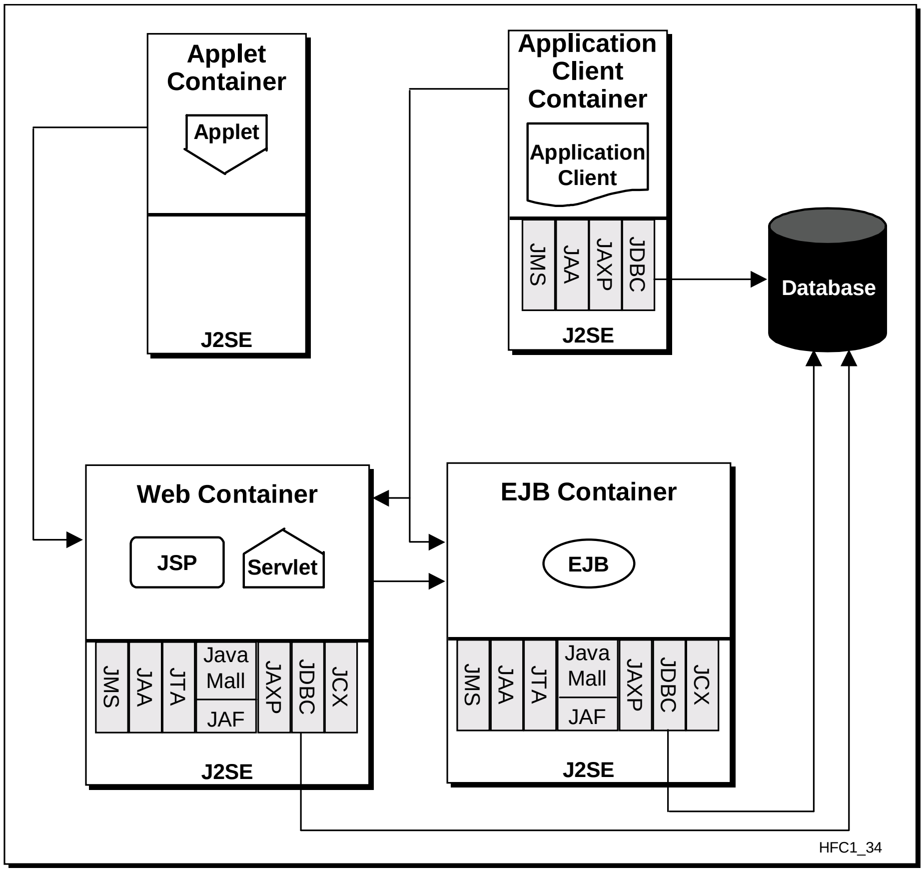
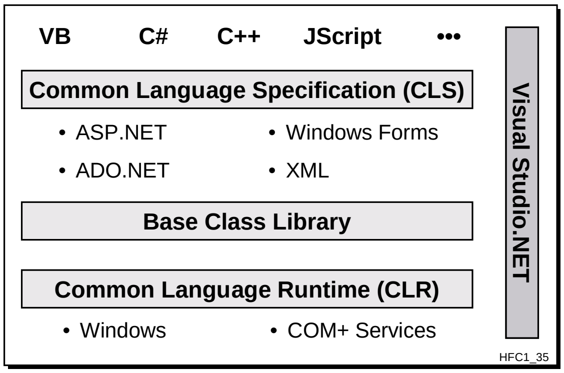


Figure 36 shows the Microsoft.Net framework (Gabriel et al., 2001), which consists of the following elements:

1. Common Language Run Time;
2. ASP.Net;
3. Windows Forms;
4. ADO.Net;
5. XML;
6. Base Class Library;
7. COM+ Services;
8. Common Language Specification;
9. Supported Languages, Visual Basic, C#, C++, Jscript, etc.);
10. Windows Forms; and
11. Visual Studio.Net.

Besides the Microsoft.Net framework, there are three other building blocks of Microsoft.Net. The first is a set of enterprise servers that handle Microsoft.Net processing. These include specific servers for each of the following: application support; databases; communications (such as email); integration with legacy host systems; Internet security;

Figure 36. Microsoft.NET Framework



e-commerce; and automation of business processes, including business-to-business communications. The second building block is a set of web services that developers can use to facilitate the administration of Internet applications. These web services include authentication, notification, and messaging; directory and search; calendar; and XML data storage. The last key building block is the integrated development environment,Visual Studio.NET, which (1) supports Rapid Application Development; provides visual designers for XML, Hypertext Markup Language (HTML), and data; (2) supports debugging; and (3) permits mixed language development.

Frameworks for distributed computing attempt to achieve a variety of efficiencies that are directly relevant to the EIM&DSS concept:

- They enhance interoperability and integration among systems and applications.
- They simplify the development and deployment of applications (partly by allowing remote access to code and information resources developed by others).
- They enable separation of software components into layers or tiers such as the presentation tier, the business or analysis tier, the database tier, and the communications or integration tier. These tiers map closely to the different layers of the EIM&DSS concept.
- They permit easier separation and coordination of roles of the people involved in the system development and implementation process. Different tiers for the most part can evolve independently while remaining coupled through the ability of objects to communicate with one another and the ability of a project manager to coordinate the roles of different personnel working on different functionality or performing

fundamentally different programming activities (i.e., web page design and software coding).

- They allow an agency to achieve a long expected life for an application (such as 15 years for an EIM&DSS) that uses components of different lifecycles and are updated or replaced as component upgrades occur or new or better components become available.

Distributed computing environments depend on certain fundamentals and a combination of open and widely used proprietary standards. Further discussion (based extensively on Alur et al., 2001; Dunaev, 2001; Gabriel et al., 2001; and Mohr and Woodgate, 2000) follows:

- **Foundation or Framework Classes—**There need to be fundamental classes of objects that developers can use for distributed systems. Classes of objects have both methods (specific types of functionality) and properties (similar to attributes). In object-oriented programming, one can extend the methods and properties of a class of objects to a new object and instantiate the object (i.e., activate an instance of the object) by using specific values of parameters for methods and for properties. Objects can include code that reveals their own methods and properties to other objects that wish to use them. An object is called a component if it is a self-contained, cohesive subset of software functionality but does not do anything unless invoked by an application. If a component includes code that renders the object in a graphical user interface or other display surface, it is referred to as a control (e.g., Active X). An object may also be a wrapper, which encapsulates and extracts interfaces and functionality of an object in order to be used by or to communicate with other objects. Objects can be abstract, public, protected, internal, private, or sealed or have similar access restrictions. An abstract object cannot be instantiated, but its methods and properties can be inherited by another object that can be instantiated. Public objects have methods and attributes visible to other objects, whereas private objects restrict access to only the type of the class containing the object.

- **Database Connectivity—**Two database interfaces are important industry standards for accessing information from relational databases. One is ODBC, developed by Microsoft Corporation, and the other is JDBC, developed by Sun Microsystems. JDBC uses abstractions and methods similar to those of ODBC. To support ODBC connectivity for a specific application, there must be an ODBC driver, and, if an application is going to access multiple databases, there must be multiple drivers. An ODBC driver manager coordinates ODBC drivers for specific ODBC-compliant databases that need to be accessed. The JDBC driver architecture is similar to ODBC and includes a JDBC-ODBC bridge driver that invokes an ODBC driver. Database connectivity to support seamless remote access of databases is constantly evolving. Various approaches have already emerged that may supersede ODBC connectivity in distributed computing environments. One is Microsoft OLE DB, which facilitates access to any data, regardless of its location and format. Another markup language for web applications is XML, which can be used to describe fully and facilitate transfer of data in any database.

- **Object Request Brokers, Assemblies, and Access Protocols—** Distributed systems need intermediaries or object managers to be able to use the methods and properties of objects that can be accessed at various locations on the network (Internet, intranet, or extranet). In the Microsoft environment, the Distributed Component Object Model (DCOM) allows Control Object Model (COM) components to communicate with each other. DCOM is an intermediate layer of software objects that query other objects to determine the nature of their interfaces. DCOM typically is used in environments where all computers use Microsoft operating systems, although there are versions of DCOM for other platforms.

  In the Java programming environment, the Common Object Request Broker Architecture that operates using the Internet Inter-ORB protocol (CORBA/IIOP) performs this intermediary function. CORBA operates on any number of platforms and with any number of languages. Both DCOM and CORBA/IIOP depend on a registry for all objects involved, including the middleware. The J2EE framework also uses Message Oriented Middleware (MOM) to allow an application to access the objects of different vendors.

  In the Microsoft.NET framework, assemblies replace the object broker; objects can communicate directly with one another using metadata in XML format. The assemblies use XML to organize the objects in an application. Other types of intermediary objects for distributed computing exist and will continue to evolve.

- **Extensible Markup Language—This is among the most important innovations that support web applications and will make efficient and widespread distributed computing feasible. XML is not a programming language but a language used to describe the structure of data in a manner suitable for web applications.** XML sets out permissible syntax, uses a parser to read an XML document, and offers the ability to develop standard data formats for a group of users (Document Type Definitions) or to use schemas (the organizational structure of data typically based on a data model). XML is based on a subset of the Standard Generalized Markup Language (SGML), which was also the basis for the widely used HTML that allows any web page to be presentable by any application capable of interpreting HTML. Major software vendors, such as Oracle, IBM, and Microsoft, incorporate XML into their database servers to facilitate description of the stored data. The J2EE framework fully accommodates XML. Also, a key to the Microsoft.NET framework is an open source industry standard known as SOAP. SOAP explains how one sends XML using the Hypertext Transfer Protocol. SOAP can be used to describe simple and complex data types, including datasets and classes, and provides a messaging envelope that uses XML to represent data in an extensible message format.

- **Server Pages—**To be useful, applications stored on a server need to format outputs so that the outputs can be read using a web browser. Technologies that have been used to do this in the Microsoft and Java environments are respectively known as Active Server Pages and Java Server Pages. It appears that these technologies will be replaced by more efficient procedures for distributed computing that will simplify programming tasks and promote good programming practices.

- **Object Identification and Management—**As mentioned above, to be useful, software objects need to be managed in a distributed environment so they can be called and sequenced in a particular order. Solutions to this problem have depended on object registries, but, in some cases, major software developers are finding other solutions such as the use of assemblies in the Microsoft.Net framework.

- **Object Directory Services—**Major software vendors, such as Sun, IBM, Microsoft, and Oracle, have developed directory services that allow vendors to register software objects that others may look up and use over the Internet. Microsoft calls its object directory services Web Services Description Language (WSDL). The J2EE framework uses the Java Naming and Directory Interface (JNDI). A “yellow page” for Internet services is the Universal Description and Discovery Integration (UDDI).

- **Remote Access—**In distributed computing environments there need to be methods for accessing objects apart from a client object. The J2EE framework uses Remote Method Invocation (RMI) application program interfaces that communicate with CORBA-compliant clients. In the Microsoft.NET framework ADO.NET and SOAP handle messaging, which facilitates the exchange of XML among remote objects or various tiers of an n-tier application.

In sum, there is little question that distributed computing will define the future information technology environment in which the EIM&DSS of any transportation agency will evolve.

Transportation agencies will need to decide at what point in the EIM&DSS development they will want to accommodate distributed computing. Initially, it may be sufficient to rely on client-server technology or an Enterprise Resource Planning (data warehouse) approach. However it will be important to plan for when data and applications are coming from many different sources both within and external to the agency.

PEER-TO-PEER FILE SHARING

Peer-to-peer file sharing may play an important role in enabling transportation and environmental managers to exchange files in ways similar to those developed for sharing music via the Internet. **Copyrights and other legal issues remain to be resolved.**

OPEN SOURCE MOVEMENT

Another technological development that deserves some consideration is the open source software movement. Many developers believe that certain types of software that represent core computing infrastructure, such as operating systems, should be published on the Internet and be available to anyone to view and update or modify. Software being developed under the name of Linux is among the software coded by developers that espouse the open source software philosophy. Certain elements of the EIM&DSS could eventually be developed under the open source philosophy.

Object Model and Software Patterns Based on Best Practices

If the agency determines to undertake an approach to accommodate distributed computing or any other EIM&DSS solution that is fundamentally object-oriented—all or in part, it is important to develop an object model and to use best practices for object-oriented analysis, design, and programming.

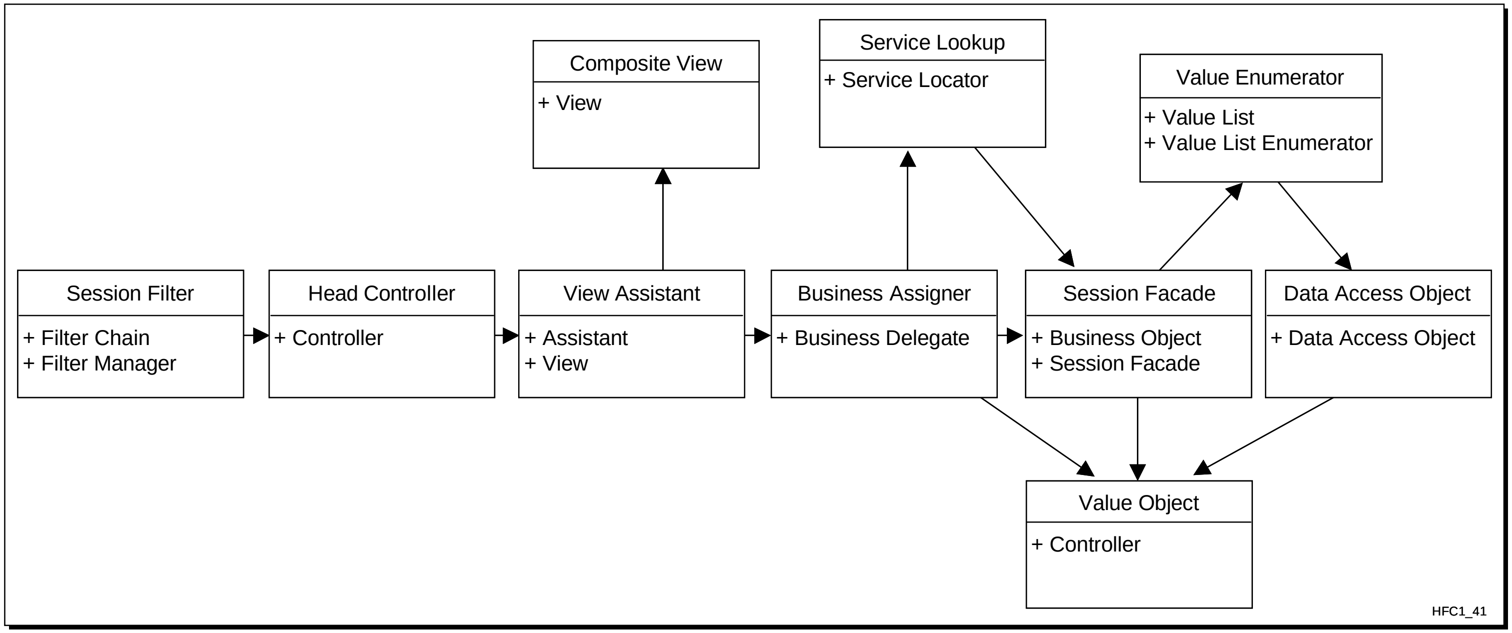
An approach that can help avoid serious design and development errors is to use software patterns that are based on best practices for design and development of object-oriented systems and applications. Considerable literature on software patterns, drawn from years of experience by leading software architects and developers, now exists.

This subsection describes a high-level object model that can be used as a starting point for more detailed specification of a software architecture for the object-oriented components of an EIM&DSS. The high-level objects represent patterns that have been proven to lead to more reliable, resilient, efficient, and cost-effective development of systems. Patterns help use prior solutions, promote reuse of software objects, provide a common vocabulary for discussing design solutions, and help define boundaries that clearly delineate roles of different people involved in the programming process.

It is recommended that an object model be developed using the Universal Modeling Language. The high-level object model of the EIM&DSS focuses on just the major entities that form the key patterns that are explained below. These patterns will accommodate evolving software technology that supports distributed computing.

Figure 37 presents an object model for much of the EIM&DSS core functionality. The object model is based on best practices and design strategies that are used with J2EE applications and other similar distributed systems. This model is intended to illustrate the type of component software necessary to support a session involving a use case where the user wants to obtain environmental management information or decision support inputs stored in the EIM&DSS database. Thus, for example, the management information might consist of commitment and compliance information or it might consist of an array of transportation and environmental impacts associated with an alternative or scenario. The following is a brief explanation of each software component (Alur et al., 2001).

Figure 37. Object View of EIM&DSS



Session Filter. This object initiates a session using a series of filters to handle security, including authorization and authentication of incoming and outgoing transactions. The session filter is also known as the Intercepting Filter.

Head Controller. The controller is the first point of contact for handling the request of a client. In this object-oriented design, the head controller handles initial processing that complements the Session Filter and, therefore, processes the request to obtain the target information. The head controller is frequently termed The Front Controller.

View Assistant. The View Assistant helps to gather data required by the view and stores intermediate values. The View Assistant component often makes distributed requests to the business tier. The View Assistant is also known as the View Helper.

Composite View. The Composite View allocates different types of data to different portions of the client's screen (e.g., content in the center, different content in the left frame, other content in the right frame, a header at the top and a footer at the bottom).

Business Assigner. The Business Assigner assists in delegating the request for information to the business tier and reduces coupling between the presentation tier and business clients. The Business Assigner hides details of the underlying business services, which helps improve the clarity of code and helps reduce potential volatility. The Business Assigner is also referred to as the Business Delegate.

Service Lookup. This component locates the service that the client needs in order to process the client request. The Service Lookup provides a sole point of control, improves performance through caching, and reduces the complexity of code. Multiple clients can use the Service Lookup. The Service Lookup is also known as the Service Locator.

Session Facade. The Session Façade helps manage workflow and the business objects and hides complex transactions (between the data objects and the business objects) from the client's view.

Value Object. This object is used to encapsulate business data. One method call is needed to send and retrieve the object, populate it with attribute values, and pass it on to the client.

Value Enumerator. Because the client may require a list of information, from some service, that may be quite large, a component is needed to manage the list. This object, also known as a Value List Handler, provides that function. This object obtains the query results that come from the client.

Data Access Object. The ability to access data depends on the source. The EIM&DSS application requires access to a database. The Data Access Object abstracts and encapsulates all access to the data source and maintains the connection with it.

STEP 6. IDENTIFY ALTERNATIVE MIGRATION PATHS

The concept for the EIM&DSS is multifaceted and complicated. **However, the EIM&DSS can be fairly straightforward to implement if an agency designs and develops it in phases. It is not feasible for either an agency or even a group of organizations to implement it all at once.**

Any organization or group of organizations that makes a commitment to work toward the EIM&DSS concept needs to select a migration path that will help it achieve its vision and then develop a phased implementation plan.

SELECT MIGRATION PATH THAT WILL ACHIEVE VISION

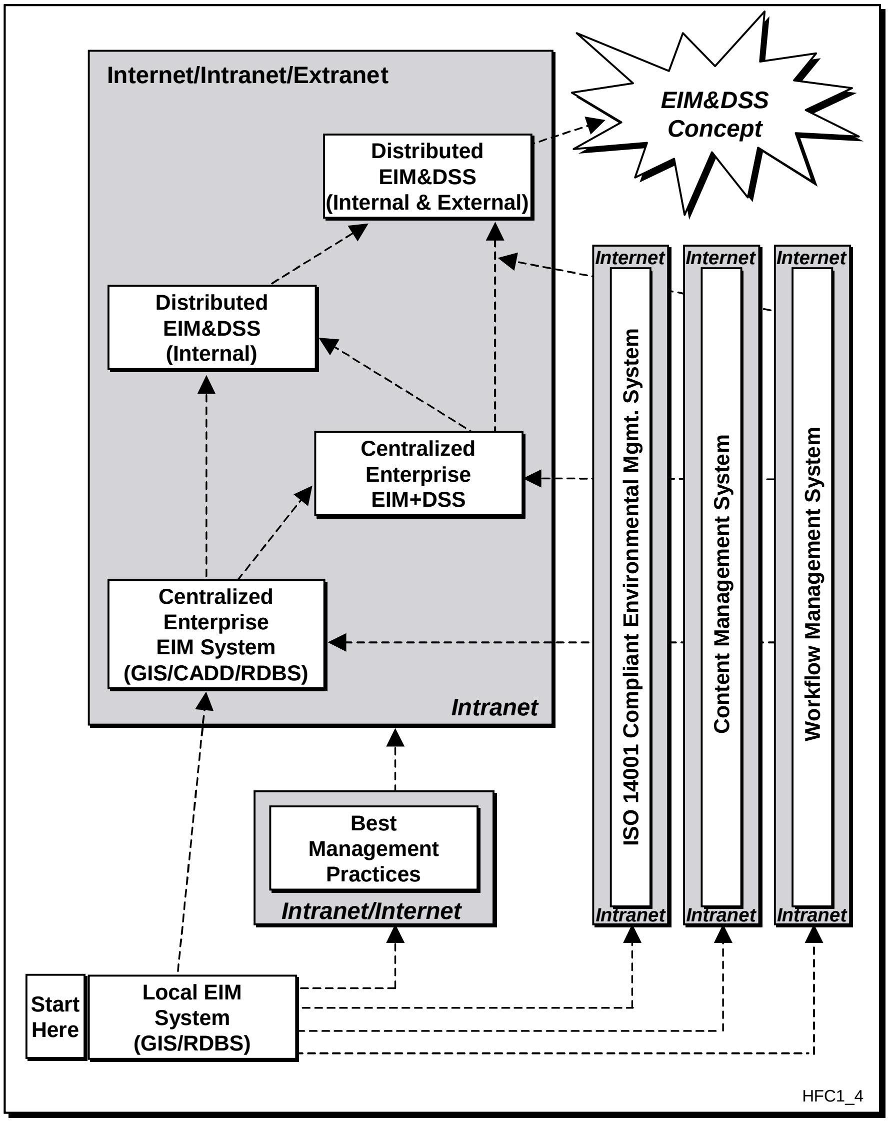
Each agency will find itself in a different situation as it begins working toward the EIM&DSS concept. This handbook explicitly acknowledges that the best steps for one agency will not be the best steps for another.

Figure 38 shows alternative migration paths for realizing an agency's vision of an EIM&DSS. In Figure 38, note that the higher up in the diagram, the closer an agency is to full realization of the EIM&DSS concept.

There are five major steps toward realization of the vision:

1. The starting point, a local or desktop EIM system consisting of a GIS wedded to a relational database;
2. A centralized enterprise EIM system composed of a GIS, CADD, and a relational database accessible over a secure intranet or other internal communications system;
3. A centralized enterprise EIM&DSS accessible by a secure intranet or other internal communications system;
4. A distributed EIM&DSS (Internal) accessible by a secure intranet or other internal communications system; and
5. A distributed EIM&DSS (Internal and External) accessible over secure Internet connections or some combination of secure intranet, extranet, and Internet

Figure 38. Alternative Migration Paths



If an agency has already evolved past the starting point, staff will need to find the appropriate starting point.

From the Starting Point. There are five relatively low-risk migration paths from here. The first path is to evolve from a local EIM system by adding a CADD system to the GIS and relational database and turning this combination of systems into an enterprise EIM system by connecting it to users via a secure intranet or other secure internal communications system. The EIM functionality can be enriched in many ways. For example, an agency can add database tables for purposes of tracking compliance with stewardship and regulatory commitments to stakeholders in scoping and other public meetings.

Another option would be for an agency to add database tables to store an array of environmental impacts that typically would be addressed in a highway-oriented EIS.

There are four other paths from the starting point. Systems associated with each of these four paths should be implemented before or in parallel with establishing the centralized Enterprise EIMS:

- **ISO 14001 Compliant Environmental Management System—** This is a performance-based planning system focused on the measurement and monitoring of customer-oriented environmental outcomes. As explained earlier, an ISO 14001 EMS consists of the following as a part of a cyclical and continuous quality improvement process: establish environmental policy, plan environmental management activities, implement and operate the EMS, check and correct actions, and conduct management review. An EMS compliant with ISO 14001 does not require a computer system. However as a practical matter, virtually every agency that implements such an EMS will use some automation consisting of at least a database.

- **A Content Management System—**This is a combination of business processes, application software, and a database management system for managing the content that any functional element of the EIM&DSS will use. The content management system is essential for minimizing one of the main risks of system failure: too much or too little data that is not useful, accurate, complete, and timely enough for users. **Often data is collected that is not needed. Too often management is unwilling to provide the resources—money, time, equipment, staff, and effort—for collection and maintenance of the content. No significant amount of data should be collected without a content management system. No element of the EIM&DSS should be implemented without ensuring that the decision support capability and the data to be collected and maintained are appropriate to one another.**

- **Workflow Management System—**This system is not essential to any phase of the EIM&DSS concept, but can enhance each and every phase. A workflow management system will lead to more efficient business processes. Such streamlining may particularly benefit environmental impact analysis and project development.

A workflow management system will help ensure that the level of detail of analysis is appropriate to the type and level of decision making required.

- **BMPs—**A web application for sharing information regarding BMPs is another element of the EIM&DSS. A web application to access BMPs is not on the critical path regarding the implementation of any other element. However, **information on BMPs can significantly improve business processes and decision making whenever BMPs become available. Information on BMPs can come in many different forms, including documents, training materials, consultants and experts, expert systems, and benchmarking results that link best practices to best performances identified through measurement.**

From the Centralized Enterprise EIM System. If an agency does not have a content management system, the agency needs to develop one first. An agency can also implement a framework for ISO 14001 compliance, a workflow management system, and a web application for accessing best practices. Once the content management system is in place, the agency can proceed along either of two paths from the centralized enterprise EIM. The first alternative path is to evolve to a centralized enterprise EIM&DSS. This includes the decision support layer capable of providing decision makers with a matrix of outcomes, outputs, and inputs for any alternative pertaining to a plan, program, project, or O&M activity for any mode. The second path is to evolve to a distributed EIM&DSS that has similar capabilities, but also has some integration with other management systems and simulation models.

From the Distributed EIM&DSS (Internal). Again, if an agency does not have a content management system, then the agency needs to develop one first. An agency can develop a framework for ISO 14001 compliance, a workflow management system, and a web application for accessing best practices, if the agency has none of these. If an agency has already attained some integration with other transportation management systems and environmental simulation models, the agency can deepen these capabilities by integrating other systems, models, and decision support tools. Consequently, users in the agency's organization will be able to access a broader set of data and obtain additional types of analytical results. From here, the main migration path is to evolve to a fully distributed system that connects the EIM&DSS to a wide variety of data, analytical resources, and decision support tools both inside and outside the agency.

From the Distributed EIM&DSS (Internal and External). If an agency has already evolved this far, then it is close to implementing the EIM&DSS concept. The agency will mainly need to enrich the EIMs so that the EIMs can carry out certain types of functionality that the agency does not already have (e.g., a capability to track compliance with stewardship and regulatory commitments made to stakeholders in scoping and other public meetings). Eventually, the agency can implement all the functionality that constitutes the vision for the EIM&DSS concept (See the discussion on building blocks in Step 7).

“Leapfrogging.” If an agency is ambitious and willing to incur substantial costs and risks, from the start it could evolve to one of the more advanced steps such as a centralized enterprise EIM&DSS or a distributed EIM&DSS. Indeed, an agency can move to one of the highest systems or the full EIM&DSS concept from wherever the agency happens to begin.

STEP 7. DEVELOP PHASED IMPLEMENTATION PLAN

Having identified alternative migration paths, an agency will need to select one that makes the most sense for the organization. Then the agency will need to identify the appropriate building blocks and assess the managerial, organizational, staffing, technical, and financial feasibility of proceeding. As the agency moves ahead, staff will want to identify short-, mid-, and long-term implementation steps.

IDENTIFY BUILDING BLOCKS

To fully understand the implementation options, it is important to have a clear idea regarding each of the important building blocks that might be implemented upon reaching any step along any migration path.

Figure 39 presents most of the important building blocks an agency will be working with as staff determine the best approach for different implementation phases. Figure 39 is based on the “upside down layer cake” presented in Figure 33.

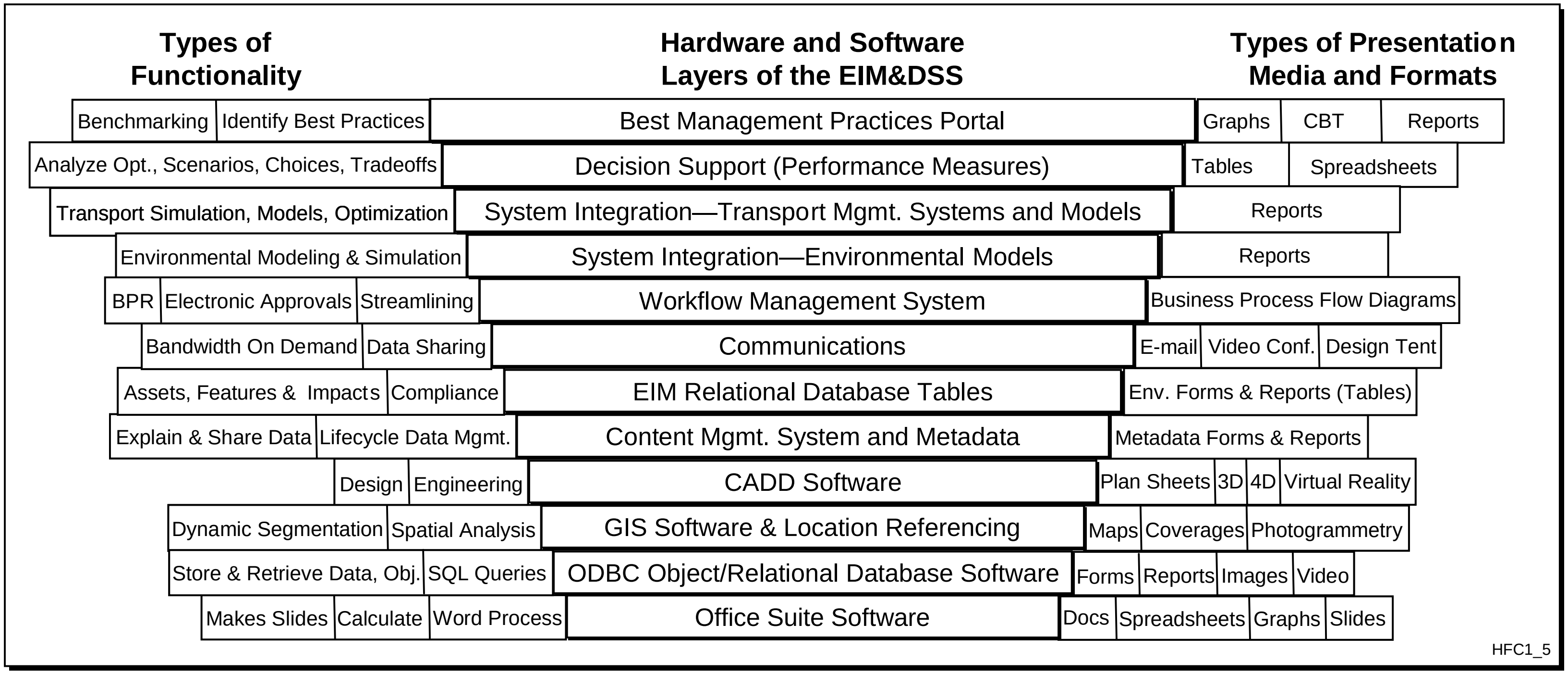
To the right of each layer are individual building blocks pertinent to the presentation of information and media appropriate for different audiences (decision makers and stakeholders corresponding to a particular use case and setting). For example, if an agency has acquired a standard Structured Query Language (SQL), ODBC-compliant database from Oracle, Microsoft, or IBM, the agency will be able to present the following kinds of information:

- Forms,
- Reports,
- Images, and
- Videos.

To the left of each layer are associated types of functionality. For example, the types of functionality associated with an Object/Relational SQL database include

- Storing and retrieving information in database tables,
- Storing and retrieving digital objects, and
- Performing SQL operations on the relational data.

Figure 39. Implementation Building Blocks of EIM&DSS



EVALUATE FEASIBILITY

Once an agency identifies the building blocks that are candidates for implementation, staff need to determine the feasibility of implementing them in the agency (or in a cooperative effort with other organizations). If staff determine that implementation is not feasible in some respect, the agency needs to find a strategy to overcome the difficulty or barrier. It is important to address the following types of feasibility:

- **Managerial—**As stated earlier, support of management is crucial to implementing each part of an EIM&DSS. **If an agency's top management does not support an endeavor of this magnitude, then staff need to obtain this support. Otherwise, staff should conclude it is not feasible. Similarly, staff will need the support of managers of each functional area of the agency that the EIM&DSS will affect.** These include the individuals responsible for

  - Planning,
  - Programming,
  - Project development,
  - Operations,
  - Maintenance,
  - The relevant modes of transportation,
  - Environmental analysis, and
  - Automation and communications.

  If the managers of these areas currently do not support the EIM&DSS, staff will need to obtain their support.

  Staff will also need a "champion." If there is no champion who strongly supports the EIM&DSS, is able to foster buy-in, work through challenges, and has lots of energy to ensure success, then it is unlikely that the agency will make significant progress. Normally the champion will also be the project manager.

  A "backup" champion is also necessary. As stated earlier, a project frequently fails because the champion is promoted, leaves for a new job, or is shifted to another assignment. It is crucial to have a backup champion.

- **Organizational—**Major systems implementation projects require strong organizational support. Management and staff need to realize the importance of sharing data and analytical procedures and overcoming stovepipe systems. In many organizations, to achieve this degree of coordination and cooperation requires organizational change. Many agencies that have embarked on major systems development projects involving systems integration do not succeed without properly addressing key cultural issues.

Similar considerations apply if an agency is developing the EIM&DSS as a part of a cooperative effort of different organizations. The participating organizations need to ensure there is sufficient compatibility and agreement on fundamental issues. There also needs to be buy-in from each of the respective agencies and an absence of technical, financial, organizational, and other barriers.

- **Staffing and Other Resources—The feasibility of implementing the EIM&DSS depends on having adequate staff and other resources. Staff requirements need to be evaluated over the lifecycle of any building block an agency is contemplating implementing.** Therefore, an agency needs enough staff to design, develop, operate, and maintain the building block. An agency also needs other resources over the lifecycle of the building block, including computers, computer-assisted software engineering (CASE) tools, suitable communications for sharing and transferring files as a part of configuration management, and adequate office and work space.

- **Technical—Has the technology evolved to the point where it is feasible to implement the building block? An agency may have a concept that is too advanced and does not currently exist.** An agency might also have an idea for a building block that is likely to emerge in the future at the time the agency intends to implement it.

- **Financial—Agency staff should perform some type of cost-benefit analysis for each building block. It is essential to estimate the monetary cost of each building block, even if staff develop only a rough order-of-magnitude estimate of costs.** If staff can develop more refined cost estimates, all the better. For example, staff should obtain price quotations for any hardware or software that is a building block.

  The cost-benefit analysis is most likely to be qualitative, but staff should make a quantitative estimate if there is an easy way to do so. Staff can develop a quantitative estimate of benefits by using a rating system that is based on a set of criteria defined by the agency. The criteria should relate to the benefits that the internal and external customers of the system receive. Ideally, staff should develop an estimate of the discounted present value of benefits to the customer over the lifecycle of a building block.

Once an agency has developed a qualitative or quantitative estimate of the costs and benefits, staff should plot these costs and benefits in a matrix like that shown in Figure 40. Plotting these costs and benefits will allow staff to visualize which building blocks represent the most easily attainable building blocks (i.e., those that are low in cost to implement and yield medium or high benefits). Staff will also be able to see easily which building blocks have high costs but low value, and, therefore, are building blocks the agency should not pursue. Finally, the agency will be able to see building blocks with potentially high payoff but have high costs and risks. Figure 41 presents a preliminary assessment of the benefits

Figure 40. Worksheet for Plotting Benefits and Costs

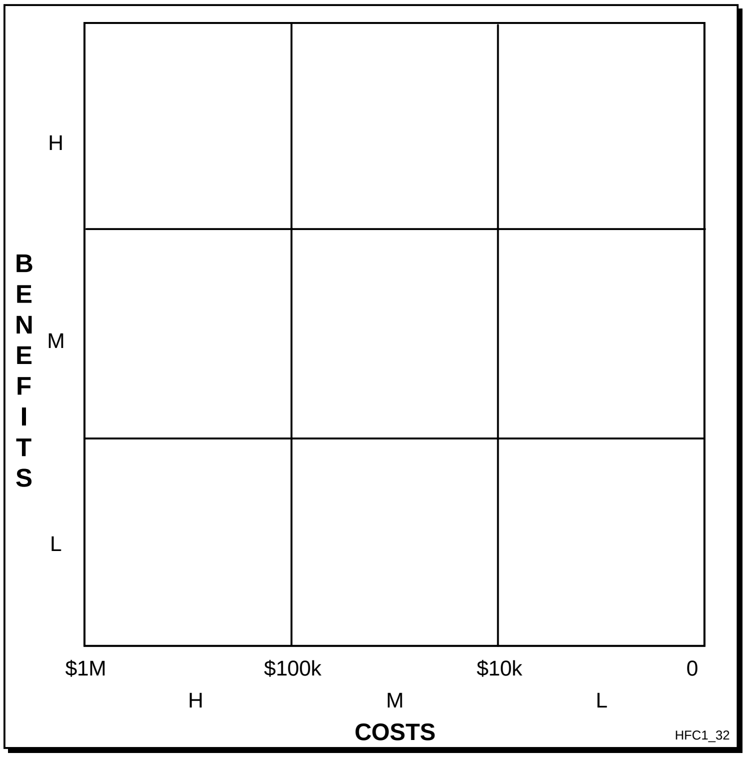
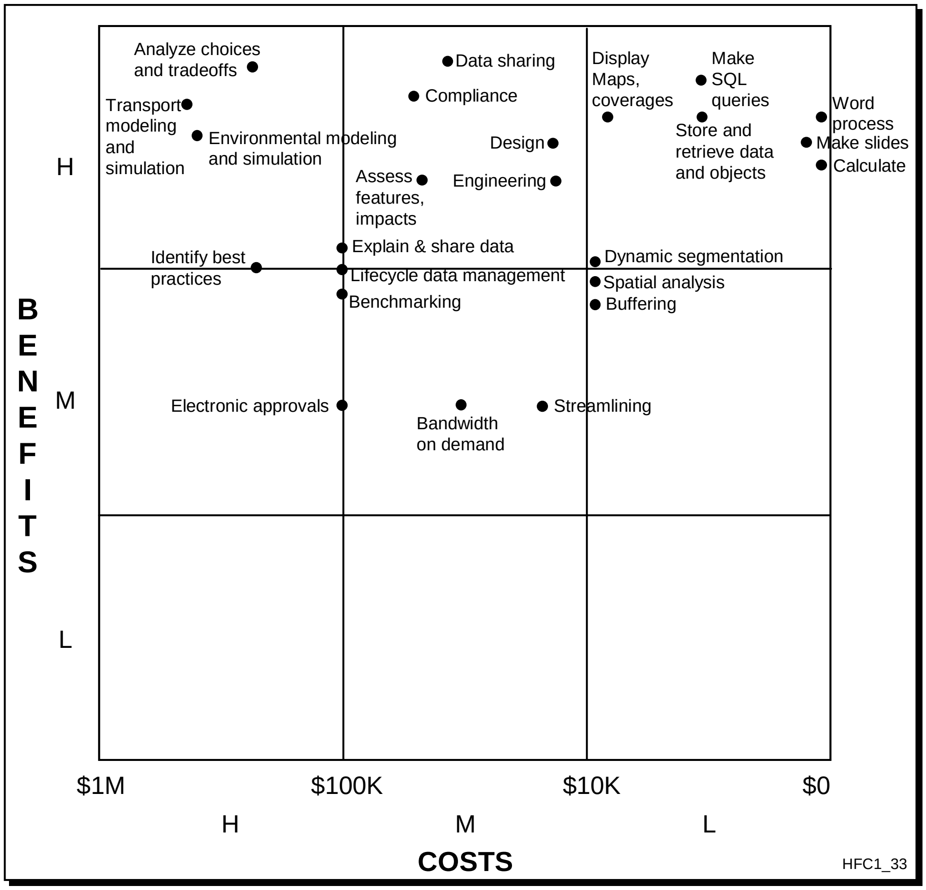


Figure 41. Plot of Benefits and Costs of Functional Building Blocks



and costs of each of the functional building blocks. The agency should assess these building blocks and any others being considered.

These are conservative, rough order-of-magnitude estimates. Agencies are assumed to have relational database, GIS, and CADD software, as well as corresponding hardware platforms. Therefore, the implementation costs for these building blocks of the EIM&DSS are low, while providing high value. Implementation of the EIM element would cost at least $500,000 and adding some basic decision support capability to address choices and tradeoffs typically addressed in an EIS as well as to provide performance reporting consistent with ISO 14001 would bring the cost to $1 million. Integration of a modest number of management systems and simulation models would be likely to bring the cost to $1.5 to $2 million, and integration of a fairly comprehensive set of systems and models could put total costs in the $5- to $10-million range.

RANK THE BUILDING BLOCKS IN ORDER OF INCREMENTAL NET VALUE ADDED

Once an agency has determined the relative benefits and costs of each building block (or package of building blocks), staff should rank the building blocks in order of highest incremental value relative to incremental cost. If benefits and costs cannot be assessed quantitatively, then qualitative methods are available. For example, personnel could use a combination of the results in Figure 41 and relevant experience to generate the ranking.

If staff have used a quantitative estimate of benefits based on some type of multi-attribute scoring system, then staff should rank the benefits according to marginal effectiveness, which is the incremental increase in the ranking score relative to the incremental costs. This ratio is functionally identical to an incremental cost-benefit ratio, which staff would use if all the benefits and costs were reduced to discounted present values expressed in dollars.

ALLOCATE BUILDING BLOCKS TO EACH PHASE

Next, define future phases for the EIM&DSS and estimate the budget for each phase.

Identify which building blocks must be implemented first in order for other building blocks to be implemented. Many of the interdependencies are clearly illustrated in Figure 33, "the upside down layer cake." For the most part, each layer should be implemented after the layer below. However, the issue is more complicated if an agency focuses on selecting functional building blocks associated with each layer. Then staff will need to conduct some type of critical path analysis.

After staff have identified the time interdependencies among building blocks, then give some consideration to which set of building blocks are logical to implement together in order to realize various efficiencies. Efficiencies can arise from consolidating different building blocks and phases in order to avoid a series of procurements of software developers. Another source of efficiencies is avoiding having to set up infrastructure repeatedly for software development for different building blocks and phases. Software infrastructure includes hardware and software for design and development and for configuration management.

Once an agency has done these things, staff should identify which building blocks or groups of building blocks are feasible to implement in the first phase (see the earlier section on evaluating feasibility).

From the feasible set of building blocks, select the ones that are best to implement until the budget for the first phase has been exhausted. Repeat the process for each phase.

Staff can allocate building blocks to phases (budgets) using informed judgment and experience or a more formal procedure.

If an agency chooses to use a more formal procedure, staff should try to order the building blocks or groups by the marginal value added relative to the incremental costs, and select every building block or group beginning from the top and proceeding down the list until the budget for the first phase has been exhausted. The building blocks selected for the first phase will tend to maximize the net value added (i.e., approach being optimal).

Repeat the process for the second phase. Rank all the building blocks or groups of building blocks not selected in the first phase according to the marginal value added relative to the incremental costs. Proceed down the list and select all building blocks until the budget for the second phase has been exhausted. Again, the choice of building blocks will approach being optimal.

Repeat allocating the budget in the same manner to each phase, until the agency has progressed through all the implementation phases for the EIM&DSS.

If staff are uncertain about which building blocks are allocated to a particular phase, staff may try sensitivity analysis—staff should vary the ranking criteria and see if the results change significantly. If an agency has the flexibility to allocate funds differently among phases, staff can explore how changes in budget constraints affect the results. Usually, there will be a pronounced effect on what to implement in a phase if the agency significantly increases or decreases the money for that phase.

IDENTIFY SHORT-TERM, MID-TERM, AND LONG-TERM IMPLEMENTATION STEPS

Once the building blocks that will be implemented in each phase have been identified, the agency should develop a schedule that shows each implementation phase of the EIM&DSS and the major milestones that will be achieved in the short, mid and long run. It is recommended that the agency use a Gantt chart or project management software to lay out the major implementation activities within the schedule. These activities should account for the following:

- Implementation of major layers and/or building blocks of the EIM&DSS;
- Actions for securing buy-in from top management and internal stakeholders (planning, programming, project development, operations, maintenance, environmental analysis, modal divisions, and automation and communications);
- Actions to secure resources (e.g., funding, staff, partners, consultants/contractors, equipment, software, communications, office space) for implementation; and
- Actions of the lifecycle software development methodology applicable to the next phase.

This last item affects the near term and is discussed in more detail in Step 8.

STEP 8. IMPLEMENT EACH PHASE USING SOFTWARE DEVELOPMENT LIFECYCLE METHODOLOGY

As an agency begins software development, a sound methodology is needed. Proven software development techniques involve methods that apply to the entire lifecycle of software—requirements analysis, detailed design, software development, documentation, iterative testing and software refinement, and finally acceptance. In the past, software developers have used a "waterfall" or "spiral" method of software development, but today best practices tend to emphasize rapid prototype development followed by incremental refinement and testing. Whatever specific software lifecycle methodology the agency chooses, the methodology should include the following steps in order to develop and implement the EIM&DSS building blocks for a specific phase successfully.

CONFIRM/REVISE REQUIREMENTS

Review the requirements for the EIM&DSS presented in Step 2, "Understand Requirements for EIM&DSS." These requirements include information on the following:

- Survey results,
- Business processes to be supported,
- Use cases to be supported,
- Functional requirements,
- Requirements encapsulated in the entity relationship diagram, and
- Synthesized best practices models.

From these requirements, extract those relevant to the next phase of the EIM&DSS the agency plans to implement.

Staff may find that these requirements need to be modified on the basis of the agency's needs or because of new needs that have evolved over time.

Revise the requirements; this revision will be the basis for implementing the next phase.

DEVELOP INTEGRATION FRAMEWORK FOR ALL PHASES AND ELEMENTS

In order to understand how the building blocks will fit into the overall system, staff will need a framework for integrating all phases and elements. This handbook offers numerous views of the EIM&DSS, but staff need to translate these views into a practical plan. Now is the time to refine the schedule for the next phase and re-examine the links between the building blocks the agency plans to implement in this forthcoming phase and the key building blocks of the previous and future phases.

SECURE RESOURCES

Now that staff have a sharper vision for and a context in which they will be pursuing the next phase, they need to secure needed resources.

If an agency is just getting started with the first phase, the following will be necessary

1. **Secure Funding—**Staff will need to get sufficient funding during the initial phases of EIM&DSS implementation. **Be sure to secure sufficient funds to cover not only development but also system maintenance.**
2. **Obtain Staff—**A project manager and/or champion may need to recruit staff to help develop the EIM&DSS, although a substantial amount of work is likely to be performed by a contractor.
3. **Establish or Join a Partnership—**If the agency is not planning to develop the EIM&DSS by itself, it needs to develop or join a partnership. This partnership might take various forms, including a cooperative project of public agencies or a public-private partnership.
4. **Establish a Development Environment—**Staff will need computers, communications, and an integrated development environment (to include some type of design studio software and configuration management tools).

If an agency is past the first phase, staff will need to ensure that funding, staff, infrastructure and other resources will meet upcoming needs.

DEVELOP DETAILED DESIGN FOR THE PHASE

Before doing any software development and coding, staff will need a detailed design. It is desirable to develop the detailed design in Joint Application Development sessions. Designers typically will review and confirm requirements and then encapsulate them in the following:

- Conventions for graphical user interfaces (GUIs) and other user interfaces,
- Input screens,
- Output screens (or standard reports),
- Navigation procedures,
- Analytic procedures,
- Database design (detailed logical data model and/or object model), and
- Application program interfaces.

DEVELOP CONTENT MANAGEMENT PLAN

Staff will need an approach to develop content for the phase that is starting. The content will depend on the analysis staff intend to perform. At the start and in the early phases, the focus will be on environmental information management, and so content management needs to be directed to informing users of the information in the database as well as its timeliness, quality, completeness, and coverage.

As the EIMs takes on an added DSS dimension, staff will need to focus more on what the decision support element implies in terms of needs for environmental information. While staff can start by just collecting data that is conveniently available, it is not wise to go too far without starting to organize data collection efforts so they are consistent with decision support needs.

DEVELOP TEST PLAN

Staff will need to test each phase of the EIM&DSS as it is being developed. It is recommended that the agency conduct an alpha test and a beta test and address any bugs found before moving to final acceptance.

The test plan should address all key use cases and business processes applicable to a particular phase and should include unit tests, string or integration tests, and performance tests.

ESTABLISH PROCEDURES FOR CONFIGURATION MANAGEMENT

An agency will need to have procedures to keep track of various versions and updates of the software. Developers will need "check-in and check-out" procedures to ensure that two individuals are not working on the same piece of software simultaneously and to keep efforts focused on the appropriate version, update, or phase.

DEVELOP PROTOTYPE AND DOCUMENTATION

Once staff have finished developing a test plan and established configuration management procedures, the agency can start developing a prototype of the system and preparing the corresponding documentation.

TEST PROTOTYPE

Test the software in accordance with the test plan. If the prototype is being developed for only a single agency, it will need to be tested and evaluated by that agency. However, if the EIM&DSS is being implemented in more than one agency, perhaps as a part of a pooled-fund effort, the EIM&DSS will need to be tested by each participating agency. The initial test is usually referred to as an "alpha test."

The software developer needs to keep track of and resolve all bugs.

REFINE PROTOTYPE

The software and corresponding documentation will need to be revised to address the bugs and key issues identified.

RETEST AND IMPLEMENT

A second round of testing, normally called a "beta test," will be required. Upon completion of the test and revision of the software and documentation, the software can be developed for application.

ACRONYMS AND ABBREVIATIONS

AASHTO—American Association of State Highway and Transportation Officials
AMPO—Association of Metropolitan Planning Organizations
ARS—address referencing system
ASP—application service provider
BMP—best management practice
CADD—computer-aided drafting and design
CASE—computer-assisted software engineering
CCTV—closed-circuit television
CERCLA—Comprehensive Environmental Response, Compensation, and Liability Act
COM—Control Object Model
CORBA—Common Object Request Broker Architecture
CRS—Coordinate Referencing System
DCOM—Distributed Control Object Model
DOT—Department of Transportation
DSS—Decision Support System
EIM—Environmental Information Management
EIS—Environmental Impact Statement
EJB—Enterprise Java Beans
EMS—Environmental Management Systems
ERD—entity relationship diagram
ESCE—environmental, social, cultural, and economic
FGDL—Florida Geographic Data Library
FONSI—Findings of No Significant Impact
GIS—Geographic Information System
GIS-T—GIS transportation applications
GPS—Global Positioning System
GUI—graphical user interface
HTML—Hypertext Markup Language
HTTP—Hypertext Transport Protocol
IIOP—Internet Inter-Orb Protocol
ISO—International Organization for Standardization
ITS—Intelligent Transportation Systems

JAD—Joint Application Development
JDBC—Java database connectivity
JMS—Java Message Server
JNDI—Java Naming and Directory Interface
JSP—Java Server Page
J2EE—Java 2 Enterprise Edition
LAN—Local area network
LRS—Linear Referencing System
MOM—Message-Oriented Middleware
MPO—metropolitan planning organization
MSDS—Material Safety Data Sheets
NCHRP—National Cooperative Highway Research Program
NEPA—National Environmental Policy Act
NPDES—National Pollutant Discharge Elimination System
O&M—operations and maintenance
ODBC—open database connectivity
OLAP—online analytical processing
RCRA—Resource Conservation and Recovery Act
RDBMS—relational database management system
RMI—Remote Method Invocation
ROW—right-of-way
RWIS – Road and Weather Information System
SDK—Software Development Kit
SGML—Standard Generalized Markup Language
SOAP—Simplified Object Access Protocol
SQL—Structured Query Language
STIP—State Transportation Improvement Program
TCM—Transportation Control Measures
TCP/IP—Transmission Control Protocol/Internet Protocol
TIP—Transportation Improvement Program
UDDI—Universal Description and Discovery Interface
WSDL—Web Services Description Language
XML—Extensible Markup Language

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Abbreviations used without definitions in TRB publications:

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