EMERGING INFORMATION SYSTEMS TECHNOLOGY FOR TRANSPORTATION

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The complexities of creating and operating transportation systems efficiently, cleanly, and safely have outstripped the ability of past experience and professional judgment alone to provide solutions. If the nation and the world are to meet this challenge, decisions must be based on considerably more and significantly better information. Information needs to be more reliable, relevant, accessible, and affordable. Better information does not guarantee better decision-making capability, but its absence surely precludes it.

This demand for information and the underlying data foundation requires new approaches to ways in which transportation agencies identify, collect, store, retrieve, manage, analyze, communicate, and present data. New concepts and technologies for information resource management, information engineering (IE), and information systems have emerged that offer unique opportunities to address the needs of the transportation industry.

Management Requirements of Intermodalism

The transportation environment encompasses a number of interrelated systems or physical facilities. Each system satisfies a demand for the movement of people and goods, which is generalized as travel. Various parties place various travel demands on the transportation system: the public sector is concerned primarily with management and enforcement, and commercial and individual travelers are interested in availability, access, convenience, cost, and safety.

Impacts, both positive and negative, result from the interaction between the facility and its use. Managing the impacts requires not only different information about each aspect of the facility and its use, but information that represents fundamentally different points of view. The perspective of a facility owner or operator such as a state department of transportation (state DOT) is different from that of a traveler, and each of these differs significantly from that of the community being affected by the facility and its use. For example, highway traffic is a capacity issue to the highway department, a utility and economic issue to the motorist, and an environmental issue to the neighborhood in which the highway is located. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) requires transportation agencies to coordinate to a degree never before achieved.

Unlike other distribution networks such as water, electric, or gas, freedom to choose a mode or to transfer between modes means that any data network must incorporate multimodal information and access. Modal authorities, however, have historically operated autonomously and often competitively, making it difficult to access and synthesize data for intermodal planning. There are many similarities in functions and data with each mode, since facilities (e.g, highways, railroads, transit, air, and water) experience similar engineering life cycles.

The complexity of managing transportation facilities is increased by the many institutional mechanisms that have evolved at the federal, state, and local levels. Any given facility has a distinct mix of jurisdictional interests and authorities, each with its own set of information needs. These needs vary over a wide range of detail, scales, and extent. For example, the detail necessary to a 911 coordinator about local restricted-access highways is different from that required by a federal economist modeling commodity flow along a designated corridor.

The most challenging issues arise not from managing facilities or traffic, but from predicting and managing interactions between a facility and its use. These interactions produce many complicated economic, social, environmental, and safety impacts.

Economic issues include the impacts on level of service for consumers, land use and value for communities, energy for the nation, and performance for facilities themselves. Environmental consequences are now taken with increasing seriousness during facility construction and operation. Air quality, noise, wetland preservation, animal habitat protection, and groundwater quality are affected and regulated environmental factors, each with its own data, impact models, and mitigation options. For example, the Clean Air

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Act Amendment of 1990 requires severe mitigation initiatives for nonattainment areas and stipulates that transportation planners explicitly address air quality during project planning.

Transportation systems affect the social fabric. They influence urban form as well as urban and rural landscapes. Transportation facilities have become ubiquitous, defining and altering the ways in which our cities grow, the neighborhoods in which we live, and the contacts that we have with one another.

Transportation Information Systems

If transportation systems are to be planned, designed, used, and managed effectively, it is evident that considerable amounts of information are necessary and that much of the information necessary to evaluate and respond to these issues does not originate in the transportation sector. For example, safety information requirements range from site-specific crash data to the route, bridge structure, and population data necessary for permitting hazardous materials shipments. Longer-term safety issues may even address the epidemiological effects of transportation on public health. Any data network must recognize this and allow efficient access to data from outside sources. The converse is also true. Since much of the decision-making on these issues occurs outside the transportation sector, the network must provide efficient distribution of data to those sources.

Transportation problems facing this nation continue to grow in complexity. Major portions of the transportation infrastructure are in need of immediate repair or replacement. Service and performance levels of new facilities are beginning to lag far behind their European and Japanese counterparts, while construction and maintenance costs keep rising. Although the traveling public has consistently demonstrated support for improved transportation facilities, society as a whole demands that such investments be environmentally sound and economically efficient.

In response, transportation organizations employ an ever-wider variety of information systems to carry out their mandates more effectively. These systems generally fall into two categories:

- Engineering systems, such as computer-aided design and drafting (CADD), photogrammetry, and electronic field notebooks; and
- Administrative systems, such as accounting, payroll, and motor vehicle records.

There have been many attempts to use conventional data processing approaches to create facilities-oriented decision support and production systems such as pavement management systems, highway and bridge inventories, safety analysis, and accident reporting that have met with limited success. These limited successes have led to perceptions on the part of some managers that the return on these investments does not meet expectations. These attempts have created large and expensive application portfolios with weak functional data and technological or organizational integration that require increasingly greater levels of resources to construct and maintain. Some have even suggested that little of what has been developed can be reused or that very little can even be easily upgraded.

Information Technologies for Transportation

Literally hundreds of technologies have applications in the transportation environment. The ones crucial to the next generation of transportation information systems include

- Data base management systems (DBMS),
- Computer server nets,
- IE (computer-aided software engineering, or CASE, tools), and
- Geographic information systems (GIS).

Each provides a foundation element for improved transportation information systems.

Data Base Management Systems

Although the application of DBMS is not new to the transportation sector, implementation has been generally limited to attribute (alphanumeric) data using hierarchical and, more recently, relational organizational schemes. From the previous discussion of transportation information needs, these schemes should be expanded to incorporate a variety of data objects (as noted in Figure 1):

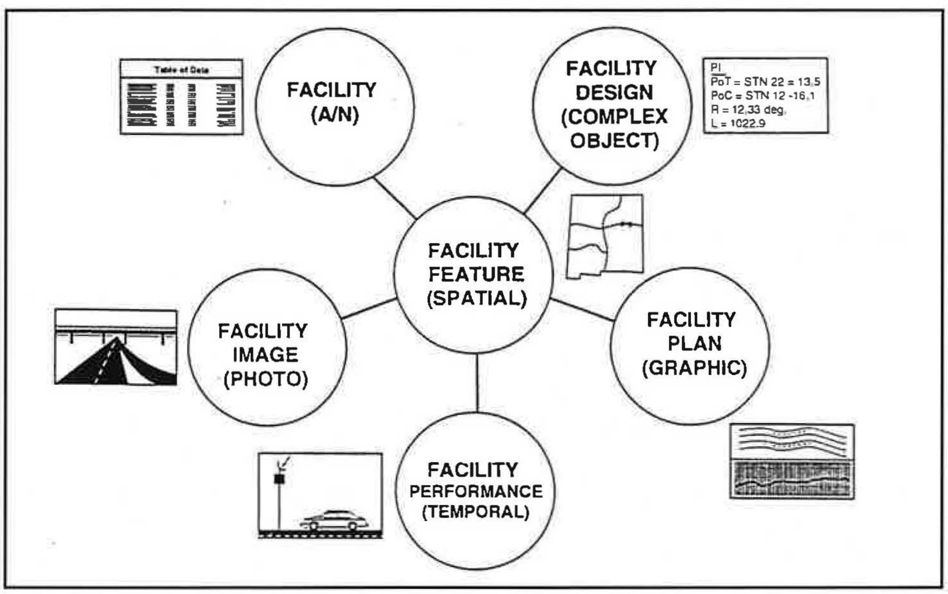

FIGURE 1 Data base management: multiple data object integration is key feature of GIS-T data acquisition and management.

• Spatial (e.g., planar and nonplanar graphs),

• Graphic (including both raster and vector types),

• Image (including multispectral images),

• Temporal (e.g., real-time telemetry, historical),

• Complex objects (e.g., CADD models), and

• Alphanumeric (data tables, descriptions).

DBMS must not only manage each class of object, but also manage relationships among object classes and create information views containing multiple objects.

Computer Server Nets

Computer server nets are an emerging computer topology replacing the historical star architecture used in traditional mainframe installations. The server net comprises many interconnected processing nodes, with each providing a custom processing "service" to the network. Such a model allows the separation of data storage, processing, and access functions.

The server net model has many advantages over other computing architectures. The concept can accommodate evolutionary, incremental system change and growth. New capabilities—such as image data bases, additional kinds of hard-copy output, expert systems, and high-resolution supercomputer modeling—can be added to a computing environment without disrupting the existing capabilities or requiring the conversion and upgrade to larger machine models.

The division of labor among nodes can be changed to balance loads. Upgrading can take place node by node, and system capacity can be increased relatively smoothly. GIS for transportation (GIS-T) can be implemented in stages, with earlier, more visible payback from initial costs.

Research undertaken under National Cooperative Highway Research Program (NCHRP) Project 20-27 developed a server net concept for a GIS-T that is a seamless stream of services with specializations at individual nodes, as depicted in Figure 2.

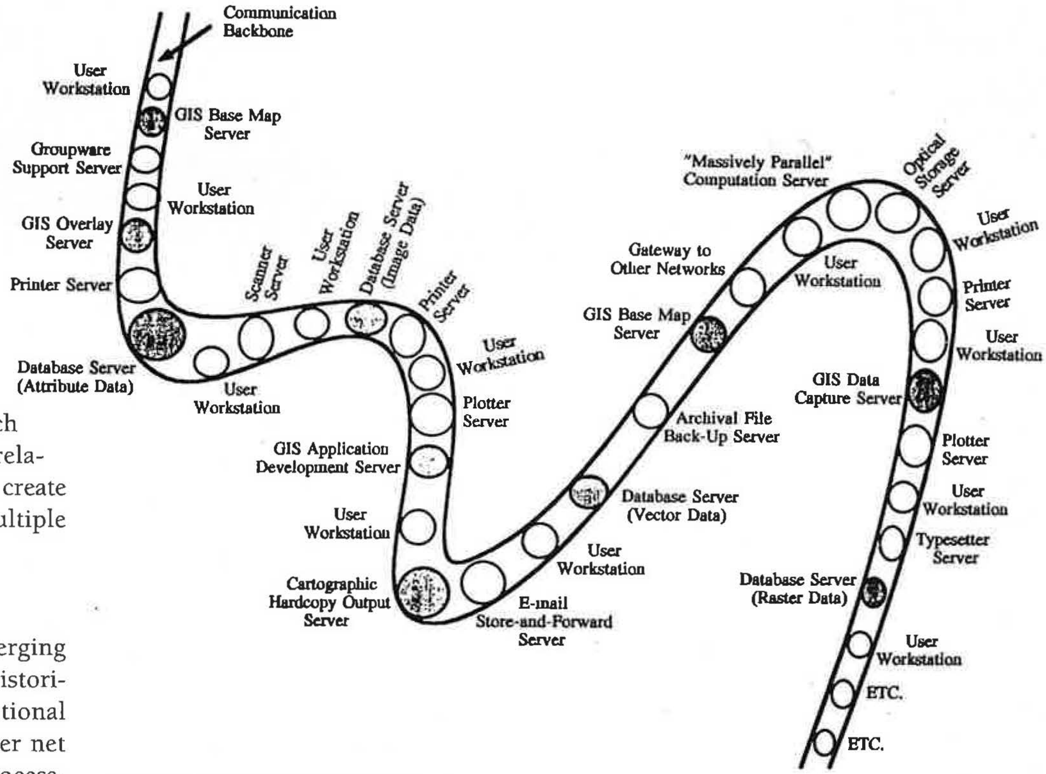

FIGURE 2 Conceptual server net model for GIS-T showing specialized nodes.

Under this server net concept,

• Network nodes are specialized, with computing labor divided among as many nodes as necessary;

• Each node operates both as a server of other nodes and as a client of other nodes;

• Nodes may vary substantially with respect not only to specialty, but also to capacity (i.e., some nodes may be supercomputers or mainframes and others may be much smaller); and

• No one node is indispensable to the functioning of the network, only to the availability of its specialized service.

Computing environments are moving almost universally toward realization of the server net model. Server nets of the near future might have labor divided so that the following functions are delegated to specialized servers: printing, phototypesetting, plotting, input digitizing, user file backup and archiving, electronic mail store and forward, gateways to other networks, data bases (with different servers supporting different data bases), user stations (with different servers supporting different users), and computation (with different servers supporting different software: e.g., statistical, finite element modeling, or linear programming).

Information Engineering

IE, a methodology developed in the late 1980s, provides a structured approach to managing information needs, flows, and uses (Figure 3). It is designed to transform the what, how, where, who, when, and why of information use into data, function, network, and organizational models or architectures. These models can then be used for work flow reengineering or for information systems development using CASE methods and tools. The models

• Identify fundamental data elements and relationships to facilitate data sharing across organizational boundaries,

• Establish and enable common processes across information systems, and

• Assist in the more effective development and use of information systems across a range of specific technology options.

	What	How	Where	Who	When	Why
Model	Data	Function	Network	Organization	Event	Motivation

FIGURE 3 Matrix framework for GIS-T prototype architecture.

The goal of IE is to provide a top-down structure identifying opportunities for data, process, technology, and organizational sharing. The end vision is to create a parts-on-the-shelf inventory of data, processes, and technologies that can be shared and reused. Bottom-up information systems development becomes one of assembly, using standard predefined parts instead of the current unique crafting exercise.

Geographic Information Systems

GIS has been defined as a complex combination of hardware, software, data, organizations, and institutional arrangements for collecting, storing, manipulating, and disseminating information about areas of the earth *(1)*. A GIS-T is a GIS dedicated to serving transportation information needs. Most transportation impacts are spatial—that is, the impact of the facility is in direct proportion to its geographic proximity to other cultural and natural phenomena. This characteristic is a primary reason that GIS is applicable to transportation. Although GIS has been successfully applied in fields outside transportation (e.g., land records management, urban planning, and natural resource management), it has been used for transportation only recently.

A recent survey by the American Association of State Highway and Transportation Officials indicated that, with few exceptions, state DOTs are pursuing GIS development with a variety of strategies *(2)*. Almost 80 percent of DOTs responding believed that GIS technology had the highest payoff potential of any identified technology, including CADD, artificial intelligence, document imaging, and end user computing. The application of GIS-T to any specific transportation purpose is denoted by a functional description, such

Transportation Research Board Activities in the Application of Emerging Information Technologies

To help address the transportation information needs of departments of transportation, the National Cooperative Highway Research Program in 1990 initiated NCHRP Project 20-27, Adaptation of GIS for Transportation.

The primary objective of the research was to develop a top-level design and implementation plan for a geographic information system for transportation (GIS-T) that would be responsive to technical (existing and emerging), economic, social, and institutional needs of transportation agencies. To use fully the capabilities of GIS-T technology, it was necessary to identify existing GIS applications to transportation and, equally important, transportation problems that could not be addressed using existing concepts and technologies.

The final report and the management guide developed in the project were published in fall 1993; they are *NCHRP Report 359: Adaptation of Geographic Information Systems for Transportation* and *NCHRP Research Results Digest 191: Management Guide for the Implementation of Geographic Information Systems in State DOTs*, respectively. A continuation of the project has been approved and will begin soon to develop generic data and functional models for GIS-T systems to provide the basis for the development of innovative applications critical to the missions of transportation agencies.

GIS-T is being explored in three other NCHRP projects as well. NCHRP Project 25-5, Remote Sensing and Other Technologies for the Identification and Classification of Wetlands, evaluates the applicability of GIS technologies in locating and classifying wetlands within transportation corridors. In NCHRP Project 14-9(4), Role of Highway Maintenance in Integrated Management Systems, concepts for an idealized framework for maintenance management information systems are being evaluated. The potential of GIS-T as a data base integrator is among the concepts being explored. In NCHRP Project 20-24(6)B, Business Systems Plan for Highway Agencies, information engineering methods are being applied to define a systems architecture. Reports on these projects are expected to be available by the end of 1994.

TRB's Technical Activities Division has supported the Committee on Transportation Data and Information Systems, which promotes research and development in this area. The committee is concerned with the development, use, and consequences of data requirements, collection methods, processing methods, and availability to support transportation research and decision making.

as pavement information system or traffic information system, as shown in Figure 4. This perspective implies that the fundamental set of concepts, mathematics, and technologies that make up GIS-T can be applied across the spectrum of transportation information system requirements.

The choice is not between developing either a GIS-T or a highway information system, but between which information technologies such as GIS-T are most appropriate for constructing the next generation of highway information system.

Emerging Information Technologies

In addition to the technologies just discussed, new technologies are emerging that should be incorporated into various information strategies. Each of these technologies, which will reach production stability or price/performance thresholds in three to five years, represents an opportunity to extend the functionality, performance, or utility of transportation information systems. They include

• Open, high-bandwidth computing networks;
• Multimedia, including high-definition true-color video;
• Low-cost mass storage devices;
• Portable cellular data terminals;
• New computing engines, including virtual reality, massively parallel processors, image processors, and neural nets;
• New DBMS, including distributed relational DBMS as well as true object-oriented DBMS; and
• Smart sensors.

Such technologies will enhance the abilities of transportation agencies to collect, manipulate, store, display, retrieve, and process data.

Conclusions

The applicability of emerging information system technologies is reflected in the following conclusions:

1. Issues facing the transportation sector are large, complex, multidimensional,

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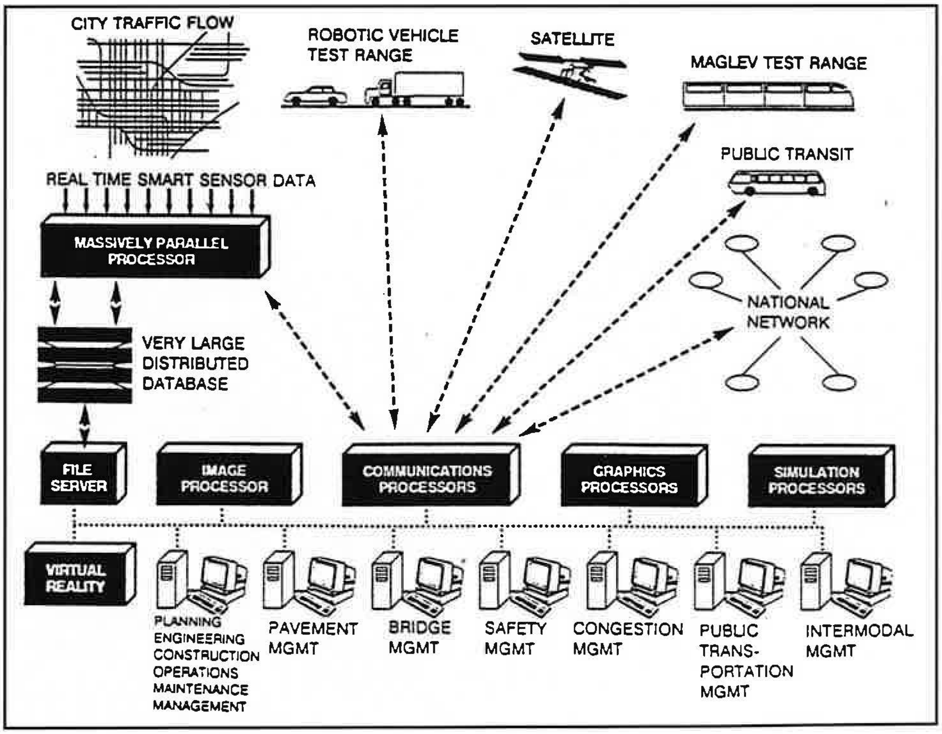

FIGURE 4 Many potential technologies must be considered for GIS-T.

Efforts of Alliance for Transportation Research

The Alliance for Transportation Research was created in New Mexico in 1991 to merge the knowledge and capabilities of the New Mexico Department of Transportation, the Sandia and Los Alamos National Laboratories, New Mexico State University, and the University of New Mexico to address transportation.

One of the first undertakings of the Alliance was to initiate a pooled funded study to develop applications of GIS-T technology for use by state departments of transportation. The Federal Highway Administration has endorsed the effort, and more than 40 states have agreed to support it. This effort was formally launched in November 1993. The primary focus of the Alliance effort will be to define the fundamental GIS-T architecture for the six management systems mandated by the Intermodal Surface Transportation Efficiency Act of 1991. The architecture will establish the basic linkage among the data required for pavement, bridge, safety, congestion, intermodal, transit management, and traffic monitoring systems.

The GIS-T effort of the Alliance will facilitate the development of fully integrated GIS-T systems to address the issues faced by transportation agencies. The effort will build on the results of research of the National Cooperative Highway Research Program in Project 20-27 and be directed by a steering committee of the participating states.

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GIS-T *continued from page 9*

Conclusions

Efforts to implement GIS-T in state DOTs are proceeding, but although more than a dozen agencies have reached the pilot project stage or beyond, only one state (Wisconsin) has successfully implemented a comprehensive, statewide management system at the district level. The next few years are expected to see significant progress in this area. The results of recent research conducted by the author and published in NCHRP Report 359, Adaptation of Geographic Information Systems for Transportation, relative to the application of this emerging technology suggest the following:

1. GIS-T can be used as a logical integrator of all types of data necessary to the transportation sector. It then becomes a central, indispensable component of an organization's overall information technology strategy.
2. The impacts of GIS-T can be profound. If exploited, it can become an integral part of everyday information processing.
3. GIS-T can support the full range of planning, design, operation, and management functions of state DOTs with the potential for significant improvements.

A number of research topics must be addressed before a wider adoption of this technology will occur. These include

1. Development of better linkage among all information technologies employed in transportation agencies;
2. Creation of new GIS-T data models, including the ability to represent three-dimensional and temporal data, to support transformation of data structures suited for information management into optimal structures for analysis and simulation;
3. Definition and support of a relationship between GIS-T-based IS (information system) and IE/CASE (information engineering/computer-aided software engineering);
4. Improvement in and productive use of networking technologies;
5. Development of GIS-T linkages to multimedia technologies;
6. Better integration of advanced data-collection technologies and GIS-T that includes real-time telemetry devices;
7. Improvement in strategies and technologies for storage and retrieval of large (Petabyte) quantities of data;
8. Design of new solutions instead of extending and adopting existing GIS technologies originally designed for other industries;
9. Exploration of the impact of GIS-T on transportation computing and decision making and ways in which organizations can exploit its potential;
10. Development of applications for transportation on the basis of the capability of GIS-T to integrate information from many sources; and
11. Coordination of efforts using a comprehensive, holistic approach to disseminate results in the transportation community.

An active information technologies industry is expected to provide new and improved hardware and software to facilitate the implementation of this concept.

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Emerging Information Systems *continued from page 6*

and interdependent. Solutions to these issues exhibit the same characteristics.

2. ISTEA represents a major shift in national transportation policy. New approaches must be implemented at all levels of government to satisfy its mandates.

3. It is unlikely that thousands of local approaches will synthesize into an integrated solution. By definition these approaches are limited in scope.

4. Although many core concepts necessary to an integrated solution have been defined, there remain unresolved issues and a need to move these concepts forward into functional prototypes before they can be used in production settings.

5. Server net concepts, IE, and GIS represent fundamentally new approaches to the information resource management problems that face transportation agencies. These and other technologies applicable to transportation are maturing rapidly.

6. Most public agencies do not have the resources to research independently the best application of technology, much less the application of new ones. Innovative arrangements are needed to promote and facilitate the implementation of these concepts.

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