Adapting Geographic Information Systems for Transportation

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A geographic information system, or GIS, has been defined in many different ways. Dueker and Kjerne (*1*) have used a Delphi process to develop a consensus definition: "A system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, managing, and disseminating information about areas of the earth."

GIS represents a new paradigm for the organization of information and the design of information systems, the essential aspect of which is use of the concept of location as a basis for the restructuring of information systems and the development of new ones. The concept of location becomes the basis for effecting the long-sought goals of data and systems integration (*2*). Conceived from this point of view, GIS-T is the union of an enhanced Transportation Information System (TIS) and an improved GIS (Figure 1). The necessary enhancement to existing TISs is the structuring of the attribute data bases to provide consistent location reference data in a form compatible with the GIS, which has been enhanced to represent and process geographic data in the forms required for transportation applications.

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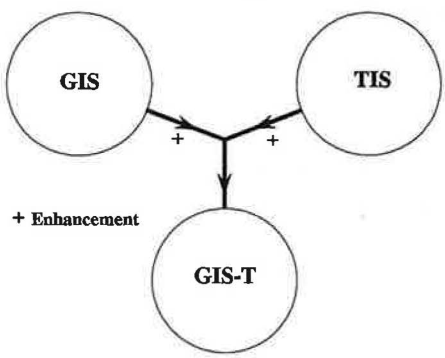

FIGURE 1 GIS-T as the merger of an enhanced GIS and Transportation Information System.

Role of GIS-T in Transportation Agencies

The major significance of GIS-T for departments of transportation (DOTs) is in its paradigm as an integrator. GIS-T is clearly a data integrator. Stand-alone data bases of the past can now be integrated as needed. This is true not only for data referenced to highway networks such as highway and bridge inventories; photologs; signage, accident records, and other safety data; traffic volumes, flows, and other operational data; and right-of-way and other ownership data. It is also true for even more disparate data such as administrative, land use, demographic, environmental, resource, terrain, and subsurface data. GIS-T does not create a single integrated data base; instead it provides a mechanism for integration to assist in solving whatever problem is at hand.

GIS-T also serves as a systems and process integrator. As shown in Figure 2 [after Adams et al. (*3*)], the components of the infrastructure life cycle management process (also the functional areas of a transportation agency) can be viewed as contributing to and extracting from a common spatial data store (*3*). Although the various components might require data at varying levels of abstraction and over varying geographic extents, GIS-T provides mechanisms for data conflation and aggregation. The major functional areas of DOTs are thus more closely bound than in earlier views of infrastructure management as a series of linearly related processes. Potential GIS-T applications span all functional areas and include

1. At the planning stage: transportation planning; pavement, bridge, and capacity management; air quality analysis;
2. At the preliminary design stage: corridor investigation, environmental investigation, right-of-way acquisition;
3. At the construction stage: construction planning, detour routing, site management; and
4. At the operations and maintenance stages: highway inventory, accident analysis, winter storm management, traf-

fic monitoring, hazardous waste routing, oversize and overweight permitting.

This process integration is consistent with Huxhold's holistic model of information needs and the business of government (4). In that model, basic data are created at the operations level, summarized for decision making at the management level, and aggregated even further for policy-making. In turn, top-level or policy decision making addresses organization-wide issues over extended time periods, management translates policy into actions, and the operations level delivers services to the public. Most of the data at all three levels are geographically referenced. This view of the relationship between information flow and program delivery leads to comprehensive information systems design that supports the organization as a whole.

GIS-T concepts are also at the heart of technology integration. The technologies depicted in Figure 3 [after Environmental Systems Research Institute, Inc. (5)] are integratable along the indicated linkages at either (a) the visual level through display-time overlays or (b) the data model level through conversion mechanisms (5). All of the technologies in Figure 3 are used to capture, manipulate, analyze, or present spatial and spatially referenced data.

The potential impact of GIS-T is profound. If this technology is exploited to its fullest, it will become widespread throughout all transportation agencies and an integral part of their everyday information-processing environments. Using GIS-T will become as usual as it was in the past to depend on long printouts from mainframe applications and as it has become to use general-purpose PC tools like spreadsheets and word processors. GIS-T has the potential to become pervasive because it provides an effective means for transportation agencies to address many of the major information management problems that they face today.

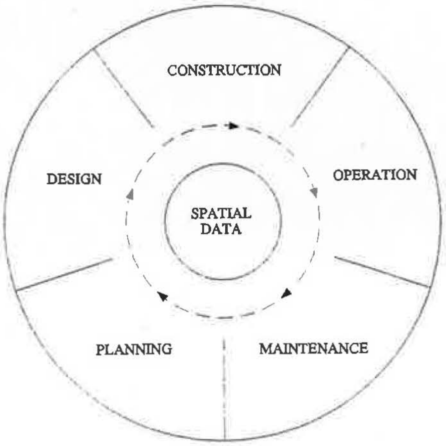

Figure 2 Spatial data are central to transportation infrastructure life cycle management.

Applications for GIS-T

To date, GIS-T has received only limited applications within DOTs, but the potential for a wide range of applications has been recognized for infrastructure management, transportation planning, design, operations monitoring, and administration. Antenucci et al. (6) state that application of GIS can lead to such benefits as (a) improvement to existing practices, (b) expanded capabilities, (c) handling unpredictable events, (d) assessment of intangible effects, and (e) sharing of information and services.

Benefits most readily arise from the reduced costs of doing business that result from enhanced productivity. GIS-T reduces or eliminates redundant data and associated activities, such as assuring that updates are applied to multiple data bases managed by different units. Single-purpose data collection, preparation, and analysis are avoided. Improved response time and efficiencies in cartographic production and updates result in lower labor and other direct costs. Production of thematic maps, such as those for traffic counts, is enhanced because there is now intelligence associated with the maps. Any attribute that is stored in a highway network data base can easily be displayed. With time series data on traffic in the data base, year-to-year changes in traffic, as well as average growth rates, can be computed and displayed.

In the transportation planning area, the benefits of GIS-T can be estimated from the reduction in time needed to create new traffic analysis zones (TAZs) or to revise existing TAZs. With GIS-T, existing geography such as census tracts and minor civil divisions can form the template on which smaller or larger TAZs can be constructed with simple editing commands. Population, households, labor force, and many other attributes can be generated for new TAZs by overlaying TAZ and census spatial data bases. Many Metropolitan Planning Organizations are still creating and modifying their TAZs manually in a process that is time consuming and error prone. Because the maps that are generated are not in digital form, they are difficult to use for analysis and links to other data bases.

An estimate of the monetary benefits of applying GIS-T to what has been essentially a manual process is provided by right-of-way litigation support in Maricopa County, Arizona (Phoenix area) (7). Without GIS-T, estimation of land value using overlays of zoning and current land use is a tedious manual process that can only realistically include a very limited set of attributes. In contrast, with GIS-T, analysis of land value can encompass the entire study area and consider all attributes in zoning and land-use data bases. GIS-T–generated estimates of development potential in an urban freeway corridor provided strong support for the Arizona Department of Transportation's (ADOT's) initial valuation of property that was subject to litigation. In at least one case, the potential savings to ADOT were $40 million (the difference between the property owner's asking price and ADOT's offer when litigation began). Manual analysis probably would not have produced the same result and would have taken longer and cost more.

Benefits are also derived when a system provides new capabilities. A multipurpose GIS-T facilitates completion of tasks formerly left undone. These benefits are the equivalent of additional staff and can be measured in labor equivalences and nonlabor costs that would be incurred without GIS-T. They result from readily integratable data bases, new analytical capabilities, and more flexible output (8). An example is the avoided costs of labor associated with the otherwise nearly insurmountable task of linking highway data and other attributes to maps and then performing spatial analysis. Benefits escalate with the complexity of the data and analysis. For example, GIS-T is well suited for the linking of land use, transportation, and air quality data and models required by recent amendments to the Clean Air Act (9). The required analysis will be greatly inhibited without GIS-T.

GIS-T has enhanced the ability of transportation agencies to estimate the risks of hazardous material transportation. Without GIS-T, detailed evaluation of a large number of alternative routes was not economically feasible. Now, lower-risk routes can be easily identified using GIS-T spatial analysis capabilities.

Some applications arise from unexpected events that are frequently faced by DOTs. For example, a GIS-T might be used to help manage an unexpected emergency evacuation even though it was not initially planned as a disaster management system. Other, more routine, as yet unanticipated applications can also arise—particularly if those conducting initial studies had little experience in GIS-T resulting in a tendency to underestimate its potential.

Intangible benefits vary widely in type and significance. They can play a crucial role in system justification. Elimination of redundant data and improvements in the quality of data reduce mistrust and lower the risk in decision making. Using GIS-T, data collected in the field can readily be displayed with thematic maps. These maps permit easy identification of many omissions or obvious errors in field data. Field data become readily accessible to operations field staff, who can then make better decisions. As a result, they are more likely to do a better job of collecting field data and to suggest new ways of collecting data that will make it even more useful. Enhanced confidence in data and decision making can lead to increased use of GIS-T. The improved planning associated with GIS-T can lead to the avoidance of future pitfalls such as planning and design failures (9). Visualization provides benefits in effectively communicating results of GIS-T analysis. A thematic map presents a comprehensive geographic view that is much more easily interpreted than a textual report, especially for large volumes of data with many comparisons.

Benefits can be derived by entering into cost-sharing agreements for data and services. Production of digital line graphs by the U.S. Geological Survey under cost-sharing agreements with state agencies is one example. Interagency data-sharing agreements can provide access to data that would otherwise require significant expenditures. Internal charge-back mechanisms for access to data, training, and services can be used to spread GIS-T costs throughout an organization.

All benefits are either direct or indirect. Direct benefits are those that accrue to the organization or unit sponsoring the GIS-T (e.g., productivity improvements and reduction of workload) (6). Indirect benefits are those that accrue to organizations or individuals not sponsoring the GIS-T (e.g., improved program delivery and service to the public) (6). Many indirect benefits can result in later direct benefits such as increased public support for an agency's program and improved credibility with the legislature.

Better program delivery and service to the public result from many factors associated with GIS-T, the most significant of which is enhanced decision making. For example, an executive information system (EIS) based on GIS-T provides a high-level decision maker with the ability to analyze the status of projects on a statewide basis in ways that were not possible before. Better budgetary planning and allocation of resources can result. This derives from integration, aggregation, and visualization of data with GIS-T. Other GIS-T applications lead to improved safety, better scheduling, and less congestion.

The benefits of GIS-T are maximized by careful and effective system design and implementation planning. A casual approach can lead to decreased benefits and possibly disaster, with large investments and restricted numbers of users and applications.

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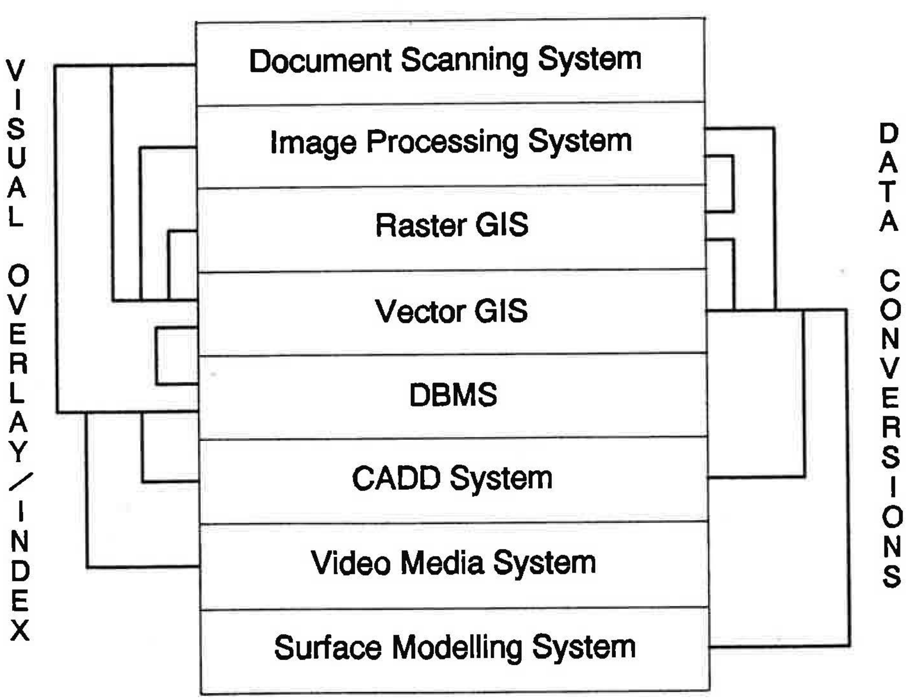

FIGURE 3 Technology integration.

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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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.

References

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