A5015: Committee on Spatial Data and Information Science
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Geographic Information Systems for Transportation
A Look Forward

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I have no way of judging the future but by the past.
—*Patrick Henry, Orator*

You can never plan the future by the past.
—*Edmund Burke, British Statesman*

The following story could be true: It's late and you're driving on an unfamiliar country road. Suddenly, without warning, a deer leaps out from the side of the road. You swerve violently, missing the deer but not the ditch. Shaken, but not seriously hurt, you wait as your car contacts E911 and requests emergency service. Within minutes, the patrol deputy nearest your car is on-scene, and a possibly serious situation is quickly avoided. Some weeks later, a safety analyst working for your insurance company observes that your incident was one of many involving animals along that same stretch of road. Reviewing recent satellite images of the area, the analyst determines that roadside vegetation has grown too close—obscuring the vision of both driver and deer. The analyst forwards a maintenance request to the Department of Transportation (DOT) and within days, the brush cutting—scheduled to coincide with other routine maintenance along the same section—is complete.

Is this story true today? No. Can this story be told within the next ten years? It depends. The outcome of this story and many similar scenarios depends on meeting significant institutional and technological challenges. One of the most fundamental is developing the ability to communicate, understand, and use information about place and time consistently across jurisdictional, institutional, and technical boundaries. The recording of places and their changes over time goes under many names—geographic information, geospatial data, geographic information systems for transportation (GIS-T), the digital earth. These digital records take many forms—maps, images, measurements, and observations—and are stored in vector, raster, and alphanumeric databases. However, for simplicity's sake, our opening story illustrates GIS-T.

GIS-T are interconnected systems of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth that are used for, influenced by, or affected by transportation activity. Many trends, directions, and influences are shaping the next generation of GIS-T. Some of them come from within the transportation industry; most are exogenous to it. While these influences represent complex, interdependent technological, political, and cultural trends, several primary themes emerge that will likely shape GIS-T in the new millennium. They include

- The evolution of GIS-T products, services, and technologies, guided primarily by general technology and market forces;
- The application and use of these products in the public sector, guided primarily by political and institutional trends; and
- Emerging data and information issues that affect those who build or use GIS-T.

GENERAL INFORMATION TECHNOLOGY AND MARKET FORCES

The nature and explosive growth of the Internet is producing an entirely new computing model. Ample evidence exists that the computing and communications industries are constructing a distributed, component-based, global network. This high-speed, broadband architecture will ultimately allow access to any desired information service or resource on an international communications network, using a variety of “plug and play” devices. In this environment, central notions of clients, services, and access methods are rapidly replacing an earlier focus on applications, products, and platforms. In essence, extensions of current technologies allow transparent access to information resources regardless of their physical or logical location. This implies that architectural and infrastructure details will increasingly be hidden behind standard network appliances, impenetrable to all except a few very large technology vendors. Information users will no longer need to know or care about the new technical infrastructure. This major trend will affect every aspect of GIS-T hardware, software, and data development.

GENERAL TRANSPORTATION ADMINISTRATION TRENDS

Governments around the globe are outsourcing, privatizing, and decentralizing many operational responsibilities previously performed by in-house staffs. Many factors are contributing to this trend, including political pressures for smaller bureaucracies, increased competition from the private sector, and the increasing difficulty of attracting and retaining qualified staff. Consequently, the inexorable future of transportation management will lie in smaller, more decentralized agencies primarily providing regulatory oversight and intergovernmental services. The public sector employees that remain will be organized into multidisciplinary teams focused on policy formulation, planning, funding, and program oversight functions. Private organizations will continue to challenge the public sector as data and service providers. This significant trend in transportation services delivery will have a major impact on the people, organizations, and institutional arrangements associated with GIS-T.

GIS-T MARKETS, PRODUCTS, AND TECHNOLOGIES

New Products, New Markets

Present Outlook

GIS-T, once the sole domain of public sector planning and transportation agencies, will continue to diffuse into broad commercial and consumer transportation markets. New products—with a wide range of features, functionality, usability, and prices—will be developed for these much larger markets. In the process, while transportation-related spatial data and services will become commonplace, GIS-T will cease to be a meaningful label. By the middle of the next decade, interoperable logistics and dispatch systems will be standard throughout the commercial transportation sector. Mobile E911 connections, map-based yellow pages, trip planning and travel directions applets, vehicle tracking and routing applications, and other real-time products, services, and applications will dominate GIS-T consumer markets. The synergy between cellular telephones, mobile positioning systems (using either GPS or cellular location technologies), and thin client computing will create entirely new markets and spatial data consumers. The next generation of personal device assistants will provide voice, e-mail, web browsing, computing, and mobile-positioning services. Mobile IP addresses, coupled with GPS circuitry attached to vehicle data buses, will provide the same set of services to vehicles.

Challenges

Although universal network connectivity is becoming a reality, serious issues remain concerning geographic data interoperability. As of now, no universally accepted data structures, formats, syntax, terminology—which constitute semantic content—or quality standards exist. Without significant progress towards standards in these areas, emergent markets may fail or, more significantly, may succeed but necessitate a much higher threshold for spatial and temporal data quality than exists today.

A major emerging issue is how to operate effectively in a world with millions of spatially enabled, Internet-attached travelers, shippers, carriers, and vehicles—each collecting and processing real-time positions locally. Users of each of these nodes will demand and expect connections to hundreds of geographic-data reference sites, including those maintained by state and local transportation agencies.

Waning Role of Public Sector

Present Outlook

Public sector (particularly federal and state) customers will wield far less influence over GIS-T products and their vendors in the future. As spatial technology vendors begin to compete for much larger commercial and consumer markets, successful GIS-T products, services, and technologies will be those that fade into the background of ordinary use. Intuitive, easy-to-learn products accessing plug-and-play data will characterize market leaders. The esoteric, complex packages on the market today will not penetrate consumer markets.

This mass “commoditization” of spatially enabled, consumer-oriented applications and utilities will be provided by vendors who have the critical capabilities—distribution channels and marketing mechanisms—required for capturing large markets. While such vendors will address consumer markets, they will not focus on transportation-specific data capture, maintenance, warehousing, and dissemination. These areas will remain the primary interest of public sector customers, offering new opportunities for the currently dominant GIS-T vendors.

Whereas today GIS-T is perceived to be too costly relative to its benefits and too difficult for the average person to use, this assessment is changing. The widespread availability of inexpensive, consumer-friendly products and services, coupled with increasing market demands for better data and better constituent service, will be embraced by public sector organizations. This will stimulate a second-generation GIS-T renaissance within agencies.

Challenges

Most public sector agencies today are encumbered with major GIS-T legacy investments and cumbersome procurement practices. Better ways must be found to create agile processes that accelerate the introduction and integration of these new GIS-T products, services, and technologies.

High Demand for Skilled Workforce

Present Outlook

A consequence of this widespread diffusion is that while spatial data and technology will be commonplace, effective knowledge about the principles underlying them will not be. Although the demand for GIS-T technologies and services will increase, the supply of formally educated spatial experts (for example, geographers, cartographers, and surveyors) will not be sufficient. Because of the difficulties in creating a “smarter” user, the tools themselves will become smarter. Consequently, most GIS-T consumers will not even know they are using GIS-T tools. More and more GIS-T functionality will be found in standard desktop software and Internet-based browsers and applets. There will be a growing number of canned applications with spatial processing components. However, this suggests that the majority of general users of GIS-T services will be content to use geographic browsing and map visualization utilities with only limited understanding and use of more complex spatial analyses.

Challenges

Although the major benefits of GIS-T arise from the application of spatial analysis techniques, relatively few people will be able to conduct these analyses with confidence. There is a critical need to create both smarter consumers of geographic information and smarter tools. A likely scenario is the emergence of two GIS-T markets: one characterized by new advances in the mapping and geographic sciences accelerated by the next generation of high-end products, and the other driven by low-end “point and click” applications. The GIS-T community needs to recognize both and bridge the gap between them.

While the emergence of high-end spatial-processing software is stimulating a revolution in the educational curricula of mapping and geographic sciences, civil and transportation engineering educators are still struggling to absorb this impact. A serious debate is needed within the profession about the role of GIS-T in undergraduate, graduate, and continuing education programs. A continued shortage of knowledgeable staff will limit the benefits inherent in GIS-T.

New User Interfaces to Spatial Data

Advanced user-interfaces will become increasingly available, particularly in high-end products. Virtual and augmented reality approaches using 3D, synthetic speech and voice activation, and other haptic devices (for example, force feedback joysticks, pressure pads, and head-tracking displays) will begin to supplant existing 2D map-oriented presentation metaphors.

GIS-T APPLICATIONS AND SERVICES

Spatial Data and Transportation's Changing Mission

Public sector GIS-T applications and services will increasingly reflect the shift in national transportation policy, from infrastructure development to asset preservation and transportation operations. While early applications of GIS-T supported project-level engineering or program-level transportation planning activities, future efforts will focus on dynamic performance evaluation and resource allocation on a system-wide basis. The Intelligent Transportation System (ITS) vision of a seamlessly integrated mix of concrete and digital components will be supported by a GIS-T foundation.

As the planning field moves more to micro-simulation models, the worlds of planning and operations will move closer together. Systems planning will become more meaningful to operations staff, and operational information will be used directly in the planning process. Planning will increasingly become an exercise in simulated operations and a new life cycle paradigm (Operate-Plan-Improve-Operate) will begin to emerge. Such changes will require implementing unified, interdisciplinary representations of real-world features and events, subsequently requiring interoperable, comprehensive, high-quality data with location and time as central dimensions. With this increasing need for current and accurate data, inconsistent or out-of-date information will no longer suffice.

Spatial Data and the DOTs

Present Outlook

The primary missions of the DOTs are evolving as well. Although they were once primarily engineering organizations closely tied to the design and construction industry, they are increasingly becoming multipurpose information providers serving a number of constituencies, including other agencies, commercial carriers, and individual citizens. The heterogeneous services they provide—engineering, mobility, retail, and intergovernmental—will be scrutinized by elected officials, the press, and the public and evaluated against a set of explicit public policy goals and objectives.

State DOTs will implement GIS-T systems to support the new services that are truly mission critical. These include systems for performance monitoring, traffic management, property management, tort cases, environmental mitigation, maintenance, setting project priorities, and scheduling.

Challenges

This unified approach to transportation system management will require major investments in transportation data warehouses that are accessible to various operational and decision-support applications. It will also require a high degree of change between operational systems and decision-support systems. Much research will be necessary to reconcile this transportation management model and GIS-T terminology and perspectives.

The need for much-higher-quality data highlights the present lack of efficient data-update and maintenance procedures. New methods of identifying changes, updating spatial databases, and communicating the changes to information service providers and end users are essential.

The application of spatial technology today is often opportunistic and tangential to core agency missions. New agency missions and objectives will require delivery mechanisms with major spatial components. GIS-T needs to become more core-mission focused, driven by critical agency needs and not by technological imperatives. This requires a degree of technical robustness and performance rarely achieved today.

SPATIAL DATA, INFORMATION, AND KNOWLEDGE

Global Data on Demand

Present Outlook

The influence of the major technological and institutional trends is also determining the future of spatial data and information. The widespread adoption of distributed object technology, plus increased software components and pervasive models of network computing using tools such as Java, will create an "on demand" environment allowing dynamic reconfiguration of spatial information. Subsequently, the type and character of data will become less important as access, viewing, and analysis methods will link transparently to a variety of data types. Spatial and other data will be dynamically allocated and organized to meet user requests; usage requirements will dictate the mix of data types and tools used in a particular problem-solving setting.

Although this will provide rapid, near-global access to unlimited spatial data, it will not do much to improve the context of resource delivery. The global spatial data infrastructure will contain a bewildering number of free and for-fee databases. Some of them will be tightly coupled to particular applications; others will be multipurpose. Users will still have to wade through all this available data searching for meaning. This creates the need for universally understood metadata or "data about data," catalogues, and other searching strategies.

Challenges

Recent lessons from existing data-intensive domains suggest that as the amount and diversity of data increases, its marginal value paradoxically decreases. Indeed, adding more data to already information-saturated situations tends to obscure issues rather than clarify them. Too much information raises extraneous issues and poses too many choices. Ultimately and ironically, the result of an expanding global spatial-data universe may be less knowledge and greater uncertainty about the world. While the promises of artificial intelligence, expert systems, virtual realities, agents, filters, and data miners are seducing us into acquiring and applying more complex and expensive information systems, we must develop better approaches to managing information glut.

Interoperable Systems

Present Outlook

Interoperability strategies, architectures, and technologies will continue to replace integrated ones. That is, the strategy of using enterprise GIS-T as a transportation information and institutional integrator will be modified to reflect more interoperable approaches. Location will continue to be an essential data dimension, along with time. However, scale and resolution differences will become less important. At the same time, data quality issues, including defensible statements of uncertainty and error, will become increasingly important. Data warehousing will accelerate these approaches, and location determination will differentiate new data-warehousing technologies necessary for transportation information processing. These will include space, time, and attribute transformations, not merely simple projection or scale adjustments. Primary data stewardship will remain with current jurisdictions, which will be using mostly existing legacy systems for data capture and maintenance.

Challenges
Metadata and public data interface standards are the two most crucial factors for determining the success of interoperable systems. Although several agencies and organizations are working on these issues, no universally adopted mechanisms exist. Metadata creation and use will be critical for true interoperability.

Location Reference Schemes

Present Outlook
Because transportation systems are essentially linear phenomena, the need to manage, analyze, and understand transportation information in a linear context will persist. However, linear referencing methods must be interchangeable with other methods of location referencing. The current trend is to collect data using two- or three-dimensional devices—such as GPS—and transform the coordinates into path-oriented or linear locations. These measurements are referenced to a standard ellipsoid model instead of base maps or linear field monuments. This allows for new economies in the field and the continued use of existing legacy and it supports path and network models, applications, and displays.

Challenges
The implications of having two fundamentally different location models—geographic and linear—are profound. Data warehouses must be able to manage both models. Improved transformation algorithms and utilities will be necessary to perform on-the-fly transformations of spatial data.

High-Spatial-Resolution Data

Present Outlook
The next generation of high-spatial-resolution satellite imagery will provide a global data source of unprecedented accuracy, scope, and availability. Since fusing vector, raster, and video spatial data structures in the application layer will no longer be a technical challenge, these images will be widely used. Specific transportation applications include creating new spatial databases, updating existing map bases, and using the images as backdrops for virtual and augmented reality displays or as control frameworks to register multiple thematic map layers.

Challenges
Widespread use of this new data in public sector transportation will depend on creative, flexible licenses; pricing strategies, plug-and-play data and applications, and “open” software and data architectures.

CONCLUSION

The transportation community has an unprecedented opportunity over the next few years to obtain, use, and distribute spatial data using many spatially enabled technologies. If utilized intelligently, the data will provide a wealth of information about transportation and its relationship to the quality of life on global and local scales. The way that we respond to today's trends, opportunities, and challenges will determine whether stories like that in our introduction come true or remain merely fables.

> The barbarians are in the line of mental growth, and those who do insist that the ideal and the real are dynamically continuous are those by whom the world is to be saved.
> —*William James, Philosopher*