INSTITUTE FOR CIVIL INFRASTRUCTURE SYSTEMS

Report on the National Forum on Advanced GIS Applications and Database Needs for Civil Infrastructure Systems

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Introduction

Those who plan, operate, and maintain civil infrastructure systems rely on a broad range of data, not only on facility location, condition, and performance, but also on land use, environmental, and demographic conditions. Advances in information technology continue to provide infrastructure decision-makers with increasingly sophisticated tools for collecting, managing, and applying this data in ways that can improve infrastructure efficiency and performance. One of these tools is Geographic Information Systems technology or GIS. Defined by the U.S. Geological Survey (USGS) as a "computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations,"[1] GIS involves geospatial database, statistical analysis, and image processing programs that integrate and visualize geographic, social, and physical data. For the civil infrastructure systems community, GIS offers a number of valuable applications, including siting and design, work scheduling, and demand forecasting. GIS has also become an important means of linking and relating infrastructure systems to one another and to communities.

Forum Purpose

As part of an ongoing effort to highlight current and stimulate future developments in this multidisciplinary field, the Institute for Civil Infrastructure Systems (ICIS), in partnership with KEYSPAN Corporation, hosted the National Forum on Advanced GIS Applications and Database Needs for Civil Infrastructure Systems on October 26-27, 2000 at KEYSPAN's headquarters in Brooklyn's Metrotech Center. The forum brought together nearly one hundred geospatial technology and infrastructure experts and practitioners from industry, government, and academia. Their presentations and facilitated discussions addressed the current status and future potential of GIS applications for infrastructure decision-making and management.

The forum was designed to leverage the experience and interaction of a group of participants with a wide range of backgrounds and interests. Approximately twenty five percent of participants represented public agencies (primarily transportation and environmental), twenty five percent represented electric utilities, just over thirty percent represented the academic and not-for-profit sectors, and about twenty percent represented the technology industry and private consulting firms. Speakers and participants offered a

[1] http://www.usgs.gov/research/gis/title.html

variety of expertise in the fields of GIS and civil infrastructure systems, including technology, engineering, public policy, and education.

The forum provided a basis for an ongoing discussion about the use of GIS in infrastructure. ICIS has developed a URL to encourage this: www.nyu.edu/icis/GISForum/.

Forum Structure and Organization

The forum began with introductory remarks by John Haran, Vice President of Distribution for KEYSPAN Corporation, Rae Zimmerman, Professor and Director of the Institute for Civil Infrastructure Systems at New York University, and Thomas O'Rourke, Professor of Civil Engineering at Cornell University and an ICIS partner. Haran spoke of the value of GIS to the utility sector as a decision-making support tool with tremendous growth opportunities. Zimmerman noted that the ICIS mission to advance the knowledge, understanding, and performance of civil infrastructure systems relies on a collaborative, interdisciplinary approach and a recognition of new approaches and technologies for improving infrastructure. O'Rourke described GIS as an important means of exploring the intersections between social and physical infrastructure and information. By refining, fusing, and graphically representing data, GIS highlights these relationships and can dramatically strengthen the analysis of infrastructure issues.

ICIS and KEYSPAN, together with a multidisciplinary planning committee, organized the forum around several primary objectives: assessing data sources and geospatial data needs related to civil infrastructure, reviewing current GIS technology applications in infrastructure and identifying barriers and opportunities for improvement, and developing a road map for research and development of advanced geospatial technologies for infrastructure. Each of the three plenary sessions focused on one of these issues and offered the insight and recommendations of several speakers. After each plenary session, Kathleen Stein, Principal of Howard/Stein-Hudson, a transportation consulting firm, and an ICIS partner, facilitated a discussion session and promoted dialogue among all participants on the range of issues raised by the speakers in their presentations.

The first plenary session, "Database Characteristics and Needs," featured presentations by: Costis Toregas, President of Public Technologies, Inc. (PTI); Martha Farnsworth Riche, private consultant and former director of the U.S. Census Bureau; and Jury Konga, principal at GEOSYS Consulting. After the first discussion session and a lunch break, the second plenary session, "GIS Technologies," featured four speakers: Julio Olimpio, Regional Manager of Environmental Systems Research Institute (ESRI); Michael Goodchild, Professor and Department Chair at the University of California at Santa Barbara; Masanobu Shinozuka, Professor and Department Chair at the University of Southern California; and Andrew Beveridge, Professor at Queens College and Graduate Center/CUNY. A second discussion session concluded the first day of the forum. The next day, the third and final plenary session, "Roadmap for GIS and Database Needs," brought together five speakers: Richard Schuler, Professor and Director of the Cornell Institute for Public Affairs at Cornell University; Bruce Spear of the Federal Highway

Administration; Michael Rogers, Project Manager at KEYSPAN Corporation; Michael Noll, Professor at the University of Southern California and the Columbia Institute for Tele-Information; and Lyna Wiggins, Professor and Department Chair at Rutgers University and President of the Urban and Regional Information Systems Association (URISA). After a third discussion session, O'Rourke offered several concluding remarks.

The remainder of this report summarizes a number of the common themes that emerged during the plenary and discussion sessions.

Applications of GIS for Civil Infrastructure Systems: Analysis, Display, Communication

During the forum, GIS was described as: a platform for evaluating spatial and multi-dimensional relationships; a data-fusion device for physical, technical, social, economic, and political information; and an integrated system for decision support. Forum speakers and participants identified a number of applications of GIS for infrastructure planning and operations. In addition to facilities mapping and asset and resource management, GIS can facilitate or revolutionize activities such as tracking inventories and assessing damage. Recent advancements in wireless and mobile devices equipped with GIS programs now offer field workers ready access to information on assets, including underground utility systems. Several speakers noted that as GIS has evolved from a digital mapping tool to a more quantitative spatial analysis and data integration tool, its applications in civil infrastructure have progressed from the project or department-specific to the more comprehensive "enterprise" orientation. A growing number of infrastructure owners are investing in network-wide GIS programs with multiple end-uses.

Because GIS links social and demographic data with infrastructure data and can provide accurate visualization of physical systems and their place in the built, natural, and human environments, it can inform and guide infrastructure investment decisions and target community needs. Census-based GIS applications can be especially useful, for example, in integrating demographic data with energy modeling and emergency and transportation planning. By providing such community analysis information graphically and translating vast amounts of information from tables and spreadsheets to colorful, readable maps, GIS also serves as an unparalleled communicative device.

In addition to linking databases, GIS can be integrated with and leverage other information technology tools used by infrastructure providers, including computer aided design (CAD) systems, global positioning systems (GPS), remote sensing, and supervisory control and data acquisition (SCADA) technologies.

Unlike traditional mapping and asset management methods which require periodic updating and upgrading, GIS provides a continuously evolving tool that can offer current and real-time information to infrastructure operators and users about anything that has a geographic footprint. This feature makes GIS valuable for demand forecasting,

customer-service, and strategic planning efforts among both utility and transportation communities.

According to several participants with backgrounds in transportation, this sector uses GIS primarily on a project-basis as a data visualization tool, rather than as a quantitative spatial analysis or data integration tool. Recently, however, a new emphasis on location-specific data, including the spatial distribution of the costs and benefits of transportation investments, has begun to promote the use of more advanced geospatial applications for transportation network planning.

Historically, utilities have used GIS primarily for mapping, design and engineering, system integrity, and network scheduling. According to utility representatives, however, GIS is becoming more valuable as a tool for data analysis and an important part of efforts to link disparate functional systems like customer service, transmission, and distribution systems. In a newly deregulated utility market, comprehensive information on physical infrastructure and demographics has become valuable to competitive strategy formation.

Lack of technology standards, difficulties with integrating new software with legacy systems, high costs, and data access and accuracy issues were cited as barriers to greater adoption of GIS for infrastructure applications, especially for analysis.

Performance and Standardization of GIS Technology

Since the 1980s, when the U.S. Census Bureau and the USGS developed the nation's first computerized street map, the costs of geospatial data technologies have decreased dramatically while the sophistication of the systems have increased. A persistent lack of standardization of GIS software and geospatial technologies, however, is commonly considered the most significant barrier to more widespread adoption of GIS applications among civil infrastructure system owners. Because the systems used to store, manage, retrieve, and apply geospatial data vary widely among agencies, sectors, regions, etc., and tend to depend on the sources and intended uses of data, advanced applications are limited by the extent to which data and systems can be shared and integrated. The incremental, fragmented, and often costly adoption of GIS technologies by local governments and agencies (who are often limited by incompatible legacy systems), and the concurrent rapid change in technologies, has thus far prevented the public sector from achieving uniform data or technology standards. The Federal Geographic Data Committee (FGDC) is working to develop geospatial data standards under the National Spatial Data Infrastructure (NSDI) that would facilitate data sharing among institutions. Public Technology Inc., a national not-for-profit technology organization, is also working to improve GIS coordination at the local and state levels. In the meantime, market-driven ad hoc standards have become more common as the software industry moves more rapidly than policy makers.

Participants recognized that the standardization and interoperability of GIS hardware, software, and data systems for infrastructure applications will require collaboration among public and private interests. The current shift in both the public and private

sectors from proprietary information technology systems to generic component-oriented systems has begun to include an emphasis on open protocols and interoperability. As individual firms, utilities, and public agencies begin to link many once-segregated activities (e.g. workforce management, customer service, transmission) within a central operations system and database, they are beginning to take advantage of these comprehensive systems and open standards. The next step is networking and facilitating the exchange of data among individual firms and agencies. According to forum participants, this will require consensus on data accuracy, access, and technology standards. While a central clearinghouse for GIS data is often cited as the ultimate goal of this standardization process, a more realistic achievement will likely involve exchange among smaller units with similar interests and the formulation of accuracy and access standards for metadata (the information about a specific set of data). One participant suggested that the Human Genome project provides an important model for a successful patchwork approach to technology development. Others argued that such an approach is still organized centrally around a shared objective and that the standardization and development of GIS will depend instead on linking smaller units with similar data and application interests.

Data Management and Policy

While improving data access and exchange is a major objective of GIS users, data access and management challenges are complicated by more than just a lack of technology and accuracy standards. As GIS and other information technology advancements have elevated data to the status of an asset or commodity, the pricing, licensing, and sharing of data have become controversial issues that, like GIS standards, have so far evolved in a mostly incremental, ad hoc manner. In the absence of any formal framework for controlling data accessibility, both public and private data collectors are generating large amounts of proprietary data with a range of approaches to pricing and privacy. Forum participants described the tension between data access and privacy concerns as a critical barrier to expanding and improving geospatial databases and their applications for civil infrastructure. As an increasing volume of local and household level data has become increasingly accessible to the public and private sectors on the Internet and elsewhere, many individuals and organizations have expressed a wariness about providing information. Some object, for example, to making property assessment, crime, or asset characteristic and location data public. While security and consumer protection concerns seem to arise most often around the collection and use of data in the private sector, they have fueled a general resistance to providing data, even for public purposes.

As socioeconomic information and information on existing infrastructure conditions become more important in determining local infrastructure needs, increased rather than restricted access to data is the objective of the infrastructure community. Some participants suggested that privacy and liability concerns have obscured data access issues and are slowing progress in developing useful GIS applications. Most agreed that there is a need to institutionalize data exchange and that a lowest common denominator approach could serve as an important first step by making broad sets of universally useful data publicly accessible. The U.S. Census TIGER files, for example, offer a

comprehensive set of demographic data for a diverse spectrum of applications. As several speakers and participants noted, a current trend of enthusiasm for data sharing is evident in efforts like Geography Network's internet site that facilitates data exchange, and New York City's comprehensive digital base map which combines data from a number of city agencies.

Participants pointed out that many of the most successful national and local GIS projects promote free and easy access to data sources through user-oriented search engines and graphical-user interfaces. As these tools increase data accessibility and facilitate the processes of applying, integrating, and manipulating data, the quality and maintenance of data becomes even more important. Just as data ownership is often hard to qualify, so is responsibility for maintaining and updating data. The concept of "knowledge management," which generally refers to business strategies related to the processing and use of an organization's intellectual capital, has only just begun to pervade the public sector. The most valuable data for infrastructure applications is often dynamic and constantly changing information on network use and performance that is generated at the local level. The potential for data misrepresentation and "lying" with GIS-generated maps could be reduced by establishing accuracy standards and promoting knowledge management strategies among even small data generators and users.

A number of speakers suggested that because most lawmakers are poorly informed about issues of data accessibility and management, public policies have failed to address the needs for both access and privacy in this new age of information technology. The GIS community could pursue a more active public policy dialogue by engaging legislators in discussions and educational sessions on these issues. Public/ private partnerships were also promoted as potentially important enablers of data management and financing policies. Participants also identified increased funding of data collection, management, and provision at the local level as a potentially important means of accelerating data exchange and standardization.

Educational Opportunities and Barriers for the GIS Profession

Forum speakers and participants addressed a number of deficiencies and opportunities in the GIS education system. GIS education and training is currently provided through undergraduate and graduate degree/diploma/specialization programs, associate degree and professional certification programs, web based distance learning courses, and vendor-based programs. Many participants voiced concern that the GIS field suffers from a general lack of skilled workers and lack of expertise among trained technicians. With the demand for skilled GIS professionals expected to increase significantly in the near future, the urgency of building and strengthening this workforce is considered a major priority. Participants agreed that today's work force is largely dominated by button pushers and code writers and lacks analysts and those with multidisciplinary backgrounds. Several participants described the disconnect between workers with primarily technical skills and those with primarily business skills as a significant barrier to implementing effective GIS programs.

Most speakers attributed GIS skill deficiencies largely to the limitations of popular vendor training programs and higher education programs that focus on teaching specific software packages rather than GIS analysis and integration techniques. A lack of consistency and licensing or accreditation among professional certificate and vendor-based programs prevents the formulation of standards or bases for comparison for students choosing programs or employers hiring graduates. Participants recommended that a collaborative effort between industry and academia should establish certification/licensing and accreditation systems and clarify the skill sets offered by different programs. Such standardization would be expected to stimulate competition and improvements in the quality of training and education. Several GIS organizations are currently pursuing proposals for evaluation standards for GIS professionals and training programs.

Recommendations for improving higher-education GIS programs included integrating GIS training into civil engineering programs and requiring a broader range of courses that address fundamental principles of statistics, data management and analysis, cartography, and geography.

A number of participants commented that they had hosted or participated in successful internship programs that offer real-world experience to students of GIS. They noted that only paid internships have proven effective and recommended more formal coordination between education and training programs and employers.

Research Needs for GIS for Civil Infrastructure Systems

Forum presenters and participants addressed both the general research needs of the GIS community and research questions that ICIS should address as part of building a National Infrastructure Research Agenda.

General Research Needs

First, speakers and participants identified a number of gaps and deficiencies in the technical capabilities of GIS that prevent the development of more useful applications for infrastructure systems. The discussion revealed a general need for improving technologies that facilitate the combination and analysis of physical and social data for infrastructure decision-making. A number of technology experts also called for efforts to develop templates that improve the integration of GIS with CAD and GPS technologies. The technology research and development wish list also included: better software for linking and integrating distributed databases, auto-correcting data, and more user-friendly interactive mapping.

Second, the forum emphasized the need to improve data collection, maintenance, and quality by reviewing best practices and establishing standards. The integration of technical and social data can yield important benefits in the evaluation or forecasting of the economic and social impacts of civil infrastructure systems. Concerns about the accuracy of data are magnified, however, when different data sets are integrated. This is

one area of research where GIS applications that use social and economic data, as well as technical data, could be extremely beneficial. Participants also suggested that research should focus on characterizing the demands and needs for information according to function because the detail and geographic range of GIS applications vary for planning, development, operations and maintenance, emergency response, and other functions.

A third area of research involves examining and quantifying the extent to which geospatial data should be made free and accessible. Participants suggested that more systematic evaluation of liability, accuracy, and financing issues for different GIS applications is necessary to better inform future investment and policy decisions.

The Role of ICIS in Advancing GIS Applications

During the break-out sessions, forum participants also identified several roles for ICIS to play in improving the research and development of GIS applications for civil infrastructure systems. These included: promoting a multi-disciplinary perspective on GIS, identifying the education needs of GIS professionals, and developing a clearinghouse for data needs.

Because of its multidisciplinary nature, ICIS could play a key role in the horizontal integration of land use planners, civil engineers, social scientists, and other practitioners that interact through GIS. In particular, several participants suggested that ICIS could improve the representation of civil engineers in the GIS profession. ICIS could assess its current liaisons to identify opportunities for better communication across disciplines.

Similarly, discussants felt that ICIS could help provide a better understanding of how multidisciplinary backgrounds are applied in the field of GIS and how priorities in the field may be changing. ICIS could also help provide a bridging function between students and employers by facilitating internship programs and identifying other mechanisms to help students of GIS gain experience with real-life practical applications.

Participants suggested that ICIS could play an important role in the development of a database clearinghouse. This could include a web-based consolidation of links and descriptions of available data sources. Such an effort would require research on data needs and standards for data integration and accuracy.

Finally, participants felt that ICIS could play a leading role in general areas of research related to GIS, such as public policy and best practices, as well as in helping to broaden current research efforts, such as the Department of Transportation's work on remote-sensing applications, by linking them to GIS development.

The following URLs were cited during the forum as useful resources for GIS users:

Federal Geographic Data Committee: http://www.fgdc.gov/
Geography Network: http://www.geographynetwork.com/
Geospatial Multi-Agency Coordination Group (wildland fire support):
http://wildfire.usgs.gov/html/geomacpublichome.html
GIS Certification Links: http://cem.uor.edu/users/kemp/certification/
Local Leaders in GIS: http://www.llgis.org
National Center for Geographic Information and Analysis:
http://www.ncgia.ucsb.edu/
Education/Certification:
http://cem.uor.edu/users/kemp/certification/
New York City Maps and Social Trends:
http://www.soc.qc.edu/Maps/index.html
Local Government GIS Sites:
City of Rochester, NY: http://www.cigis.rochester.ny.us/
Westchester County, NY: http://giswww.westchestergov.com/