Innovations in Geographic Information Systems Applications for Civil Engineering

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Innovations in Geographic Information Systems Applications for Civil Engineering

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Since their inception, computer-aided cartography (CAC) and geographic information systems (GIS) have facilitated the development of maps on demand. However, only during the last decade and a half have many disciplines embraced the power of GIS in maximizing the use of spatial data to solve discipline-specific problems that are traditionally solved by using conventional computing and manual methods. GIS has also penetrated into engineering practice and research to the point that many traditional civil engineering applications are now available only on GIS platforms. For example, transportation planning and travel demand modeling exercises are routinely conducted by using such software packages as Citilab's CUBE and Caliper's TransCAD, both of which are based on GIS interfaces.

Despite the progress, analytical engineering tasks are often tackled with application-specific tools that may or may not contain GIS interfaces. In general, penetration of GIS is more prevalent in performing visualization tasks than in conducting engineering analysis, design, or management. In other words, the full potential of GIS applications in civil engineering has not yet been realized. As a leading journal in its class, the ASCE *Journal of Computing in Civil Engineering* (*JCCE*) frequently features relevant articles on GIS in civil, environmental, and water-resources engineering. The purpose of this editorial, thus, is twofold:

- To provide a focus on developing innovative GIS-based solutions for civil engineering problems in general; and in particular, for transportation, environmental, and water resources problems
- To provide guidance to potential researchers for submission of GIS-related papers to the *Journal of Computing in Civil Engineering*.

Examples of GIS-Based Solutions for Civil Engineering Problems

Many GIS-related projects involve the simple application of GIS tools and methods. Examples of "simple application" projects range from developing a thematic map to automating a manual or semiautomatic process in a GIS environment. Such processes are similar to developing a computer program for automating an otherwise repetitive process (e.g., defining watershed boundaries). However, an ample need exists to develop innovative GIS solutions to more-complex engineering problems. The application areas for such solutions include land development, surveying, construction management, infrastructure management, environmental planning, transportation planning and engineering, and infrastructure security.

Surveying, site development, utility layout, and other land-development tasks are examples of applications that are traditionally performed by using computer-aided design (CAD) software. However, utility networks such as sanitary sewer and water distribution networks are managed by using GIS software. This dichotomy exists although several GIS software tools (such as ArcGIS) can also be used to develop CAD solutions, while at the same time, CAD software can also be used to perform some elementary GIS mapping and data management. There are inherent advantages to performing both design and informatics in one platform. Currently, CAD drawings of the site layouts are converted to GIS layers after the approval process. An innovation in this area might be a land development and site design project that can seamlessly be featured in a GIS environment with existing layers.

Among all civil engineering disciplines, the use of GIS is particularly prevalent in transportation engineering. The United States Census Bureau's decision in the mid-1980s to topographically encode the entire road network in the United States (i.e., the TIGER line file network) has had several positive ramifications for the increasing use of GIS for solving transportation engineering problems (often referred as GIS-T). Furthermore, the U.S. government's decision to make GPS technologies available for public use has helped in the explosion of integrated GPS and GIS solutions for a variety of engineering and commercial applications. Thanks to the prevalence of in-vehicle navigation systems, even the general public is now aware of the power of integrating GPS technology with GIS. Such successful commercial GIS applications as routing have created the need for additional data along the road network.

Transportation (road, rail, water, and air) networks are represented as vector-based line layers inside GIS. Using these digital networks as the base, many network models such as path-finding routines and traffic assignment models have long been successfully implemented on GIS platforms. Recent innovations in GIS-T include successful application of dynamic segmentation data models for a number of transportation problems. Included among these successful applications are integrating detailed highway crash data with roadway link segments or asset management for traffic control devices.

In conjunction with transportation engineering, the practice of water resources engineering has been propelled by advances in GIS technology. Physically based modeling of surface and groundwater processes is data-intensive, requiring representative layers of terrain, land cover, imperviousness, and soil conditions, as well as estimates of channel and subsurface conditions. Storage and manipulation of this geospatial data is commonplace in GIS,

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as are terrain-processing capabilities for watershed delineation and automatic feature extraction (e.g., slope and flow-length calculation). A sea change is apparent in the application of GIS for water resources, marked by the promise of fully integrated hydrologic, hydraulic, and geomorphologic analysis; rainfall and runoff modeling based on unit hydrograph theory; and mixed modeling of extreme-magnitude events. These areas will require expanded research in computational methods.

In the past, the most significant research into the development of geo-object models for watershed systems has made integrated modeling of hydrologic, hydraulic, and geomorphologic analyses possible. The ArcHydro data model, for example, provides a topologically integrated framework of catchments and river segments that can be used to simultaneously model surface and subsurface runoff, channel routing, and erosion processes. Parameters can be directly referenced back to the object model, thereby enabling integrated sensitivity analysis. In the past, separate models were often developed to support each type of analysis. The incorporation of time series into the hydrodata models allows time-versioning of geospatial data and a shift in the role of GIS as a preprocessor to a spatial/temporal engine for modeling integrated watershed processes.

One engineering application of water resources has been to support transportation design such as in bridge development. GIS has enabled a transition away from modeling for "design storms" and to watershed-specific runoff conditions. Hydrometeorological data from *NOAA Atlas 14* (NOAA 2004), combined with measures of basin-specific runoff response, allow for unit hydrograph models that provide more accurate representations than regional methods. Such models can only be derived from GIS data and require research in automated calibration procedures, a potentially challenging computational problem.

GIS support for the hydrologic and hydraulic modeling of extreme high-flow events is common. The application of GIS for modeling low-flow conditions is increasing. The field of ecohydraulics has emerged to consider flow conditions for in-stream and riparian flora and fauna. An emerging research need is determining how GIS can be used to support the spectrum of extreme-magnitude events and the computational aspects that are involved.

GIS Articles for *Journal of Computing in Civil Engineering*

In describing the current and future practice of computation and GIS applied in civil engineering, it is apparent that existing practice is driving GIS software technology to support modeling. *JCCE* has published several articles related to GIS use in the civil engineering domain. Some of the recent GIS articles appearing in *JCCE* include a wide range of topics, such as safety assessment of highway stopping and passing sight distances (Khattak and Shamayleh 2005), Web-enabled geotechnical information system on a GIS platform (Kunapo 2005); data-quality issues for distance measurement (Rasdorf et al. 2003); and integrating GIS and hydrologic modeling (Xu et al. 2001).

We are now seeing that the capabilities of GIS are driving the advancement of our engineering models. Our goal is to publish more high-quality research articles in *JCCE* that will further advance the use of GIS in civil engineering practice and research. With this in mind, it is especially appropriate for authors to submit research papers to the *JCCE* on the following representative topics.

- Inventions in AM/FM mapping solutions for such civil engineering applications as construction and the management of utilities,
- Integrated GIS and GPS solutions for engineering problems,
- Remote sensing data and GIS,
- Intelligent transportation systems,
- Environmental planning and remediation,
- Engineering management,
- Land development engineering,
- Infrastructure security, and
- GIS for the management of wireless sensor networks.

The preceding list is not an exhaustive one. Although most GIS-related projects tend to be applied in planning, a research article describing GIS innovations for professional engineering might include some or all of the following:

- A well-defined problem in which the application of GIS clearly and directly addresses deficiencies in the system or in engineering practice;
- The data model of a GIS-based system, including instances, in which existing and new data sources are clearly identified and data collection methods are outlined, along with the specification of relationships among the data elements;
- A discussion of other technical issues related to hardware, software, and data management for GIS;
- Details of the study methodology discussed in enough detail to avoid ambiguity;
- Results presented with supporting exhibits, including tables, charts, and appropriate maps;
- Conclusions that are based on the data and supported by results of both the study and previous research; and
- Contributions to research and practice in engineering that are clearly stated and justified with data.

The purpose of this editorial is to encourage research in the GIS area and to encourage authors to carefully consider the contents of GIS-related articles to be submitted for publication in *JCCE*. Significant opportunity exists in this area, and your participation in *JCCE* GIS activities is encouraged.

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