Spatial Decision Support Services Enhance Homeland Security

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A comprehensive spatial decision support system that helps local, state, and federal agencies allocate technology and personnel can reduce the United States' vulnerability to terrorist attacks and natural disasters, particularly at international borders.

MING-HSIANG TSOU, DOUGLAS STOW, AND JOHN KAISER

The purview of the U.S. Department of Homeland Security includes the prevention and mitigation of terrorist attacks, recovery from natural hazards, and response to industrial hazards from chemical explosions, nuclear powerplant meltdowns, and train wrecks. Using spatial information technologies to enhance collaboration between local and federal government agencies, prevention and mitigation tasks can be accomplished in a more timely and efficient manner, thereby reducing the nation's vulnerability to such events. Here, the authors introduce a design for a fully integrated cyber infrastructure and a technology framework to accomplish the major tasks of homeland security.

REASoN Research

Aspects of the technology frameworks discussed in this article are derived from a NASA (National Aeronautics and Space Administration) Earth Science REASoN (Research, Education, and Applications Solution Network) project at San Diego State University. The project is assisting with the development of a border spatial decision support service (BSDSS) for improving allocation and deployment of security resources along U.S. borders.

Security agents with U.S. Customs and Border Protection (CBP), state and local law enforcement and resource protection agencies, researchers from San Diego State University, and remote sensing technology companies are collaborating on this project. The goal is to develop a BSDSS that can be used by all levels of personnel within CBP and collaborating local, state, and federal agencies to tactically and strategically allocate and disseminate personnel and technology resources for securing the international borders of the United States.

In a comprehensive BSDSS framework, timely satellite data can enable security agents to assess changing border conditions. These may include such natural hazards as weather or wildfire events; changes in transborder surface routes, patterns of apprehensions, or sensor enunciation patterns; or shifts in the deployment of mobile enforcement resources, location of border incidents, or patterns of environmental degradation. Mobile communications equipment, Web-based geographic information systems (GIS), spatial models, and remote handheld computers with Global Positioning System (GPS) technology can link via encrypted communications directly to the BSDSS to facilitate resource allocations and enforcement actions.

It's important to note that some technology integration tasks mentioned in this paper have not been fully implemented and are in the exploratory stages of the REASoN project.

Key Components

The three major components of the BSDSS are:

- A GIS data portal connecting to multiple GIS data warehouses

Ming-Hsiang Tsou is an associate professor, **Douglas Stow** is a professor, and **John Kaiser** is in the Department of Geography at San Diego State University. They can be reached at mtsou@mail.sdsu.edu, dstow@mail.sdsu.edu, and jkaiser@geography.sdsu.edu, respectively.

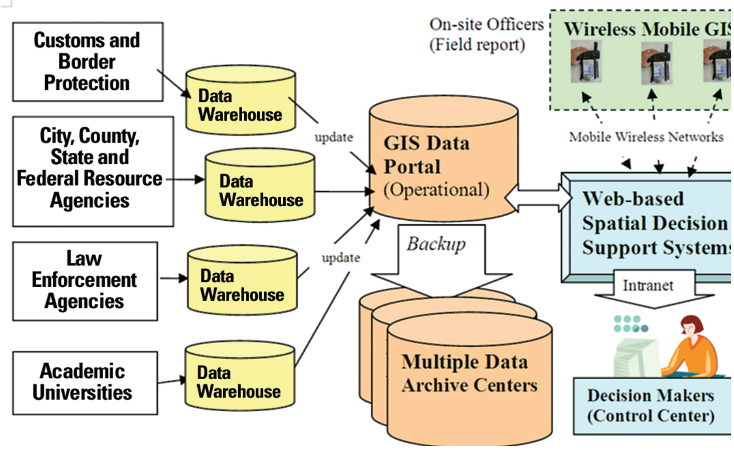
■ A Web-based user interface linking to advanced spatial decision support systems

■ A wireless mobile GIS providing near–real-time transfer of information between field agents and the BSDSS.

Figure 1 illustrates the overall architecture of the BSDSS, which combines these three components with external, secure, GIS data warehouses. The core of this service framework is the Web-based BSDSS, which can use the GIS data portal to access multiple distributed GIS data warehouses and wireless mobile GIS carried by field agents.

The GIS Data Portal. The Web-based GIS data portal provides access to multiple GIS data warehouses from distributed organizations (city, county, state, and federal law enforcement and resource protection agencies, as well as academic institutions). A centralized access point (data portal) can use distributed database connectivity to automatically fetch the most recently updated data from remote data warehouses located throughout multiple agencies.

The GIS data portal then backs up these data into multiple data archive centers across the networks. The portal will be used to provide comprehensive databases and map layers for advanced spatial analysis and GIS operations. The advantage of having a single database connection channel between the BSDSS and GIS portal is improved reliability. If any distributed data nodes (servers) are not available during an operational runtime due to system shutdown or networking problems, the GIS data portal will retrieve archived datasets from one of the multiple backup data archive centers. Each center is located in a geographically distinct site.



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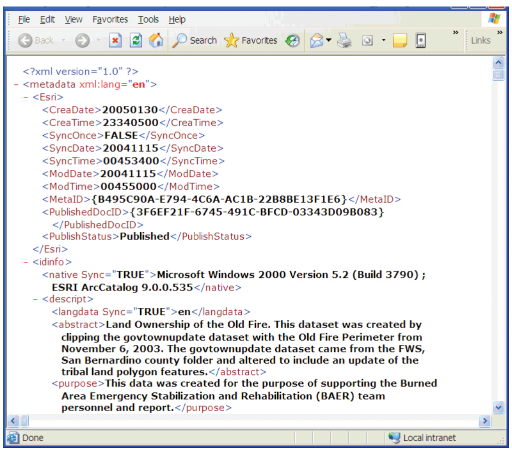
▲ FIGURE 1. The integrated BSDSS framework (modified from Tsou, 2006, p. 318)

One major challenge in developing a comprehensive GIS data portal is ensuring the inclusion of complete metadata descriptions for every data item (Peng and Tsou, 2003). Different agencies and organizations might have different metadata formats and GIS requirements. It's a major challenge to integrate these heterogeneous metadata formats and GIS databases into the GIS data portal. One possibility is to adopt FGDC (Federal Geographic Data Committee) metadata standards and store these metadata records in extensible markup language (XML) format (see Figure 2). The XML-based metadata format offers flexible and advanced query functions.



▲ FIGURE 2. Comprehensive XML-based metadata files for each GIS layer.

Web-based User Interface. The second component is the design of a Web-based user interface to provide advanced spatial decision support services and functions (see Figure 3). Most traditional versions are closed systems with an ad hoc user interface designed for specific hardware and operating systems. The BSDSS incorporates a new service framework to provide more flexible and customizable services for decision makers. A major advantage of Web-based user interfaces is that they can be customized for different users and different tasks. They're upgradeable to incorporate future Web technology changes.

There are two major challenges in the design of the Web-based user interface for the BSDSS. The first is the large data volume associated with remotely sensed images when they are displayed from map servers. Most commercial Internet map servers have limited capability to serve large image files (more than 100 GB) directly. However, some image compression and tiling technologies are beginning to provide effective solutions to this problem.

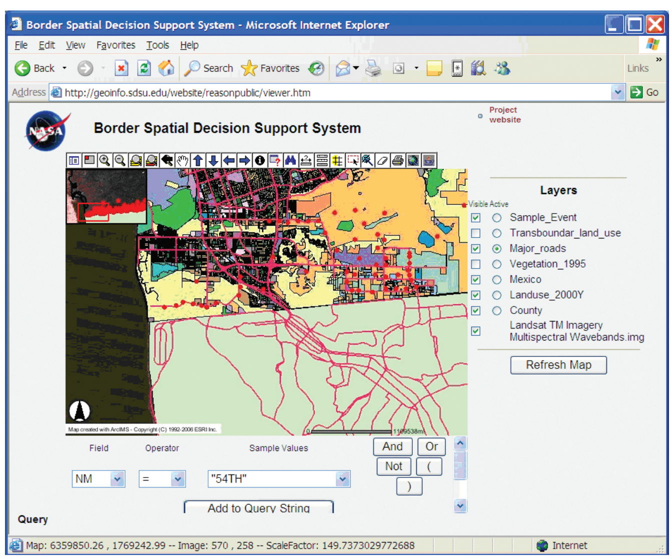
The second challenge is to provide advanced spatial analysis and GIS modeling functions for the decision support system users. Most Web-based GIS can only provide a limited set of GIS functions, such as buffering and spatial query, due to computational loads. Network and overlay analysis and three-dimensional mapping are rapidly improving as Web GIS technologies evolve.

Wireless Mobile GIS. The third component is the wireless mobile GIS element with encrypted channels, which transfers near–real-time information from remote locations to the Web-based BSDSS. Mobile GIS services can provide geospatial information and GPS coordinates for field-based personnel conducting GIS tasks remotely (Tsou, 2004). They can combine GPS and satellite images to assist local government and emergency response teams in identifying potential threat areas so officials can demarcate critical "restricted zones" (see Figure 4). Near–real-time spatial analysis models supported by GIS can be used to generate the most effective evacuation routes and emergency plans during natural hazard events (Tsou and Sun, 2006). Wireless Internet-based GIS can also assist public policy officials, firefighters, and other first responders in identifying areas to which their forces and resources should be dispatched.

To accomplish these goals, it is important to introduce these new mobile technologies to emergency management personnel and related organizations. Emergency managers and first responders must also understand both the advantages and the limitations of GIS technologies in disaster management

Analyzing Remotely Sensed Data

A primary focus of the REASoN Project is to use remotely sensed data to analyze border security.



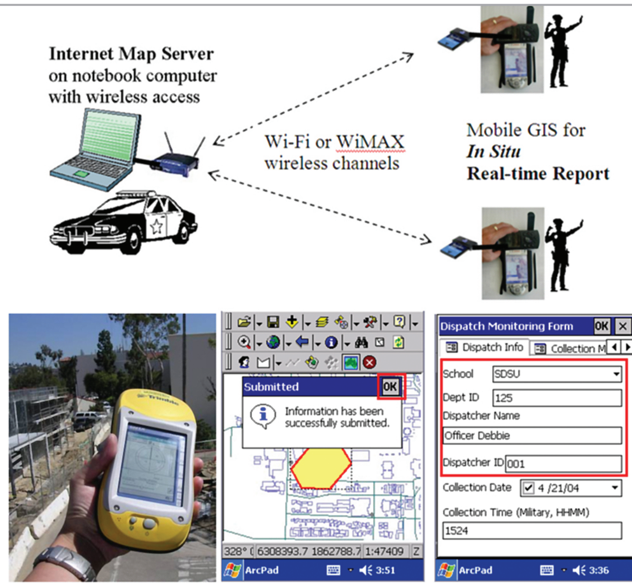
▶ FIGURE 3. The beta version of the Web-based BSDSS interface.

Such data, in combination with field personnel conducting remote observations, can be integrated with wireless mobile communications for rapid dissemination of information through the BSDSS to decision makers and field operatives.

Using remotely sensed imagery in combination with integrated spatial decision support services allows three major assessment tasks to be performed and the results distributed in a highly efficient manner. These tasks include validation of features observed on remotely sensed imagery (groundtruthing); assessment of changes in the distribution and characteristics of geographic features, land cover, and terrain (image-based change detection); and the allocation, deployment, and management of emergency response resources.

Field observation of remotely sensed land cover, landforms, and surface objects allows validation of basic terrain characteristics needed for emergency response and preemptive planning. Knowing with certainty that landforms and current land cover types are accurate is fundamental to responders' ability to maneuver, observe, and perform. Such knowledge is also required when assessing routes taken by smugglers, terrorists, and natural hazards.

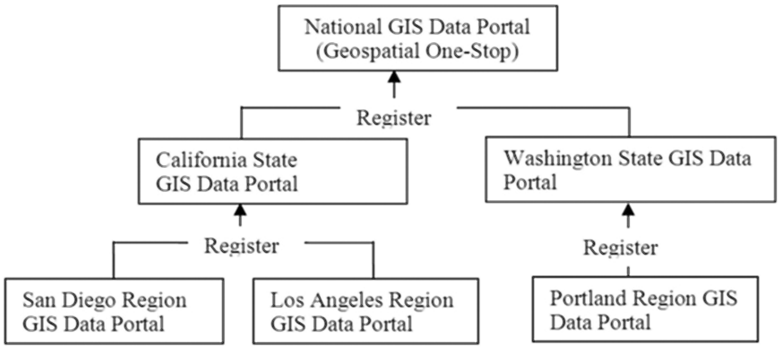
Detecting and validating changes to baseline landscape conditions is essential to assessing and incorporating such changes into the planning and response processes. This type of activity is well suited to the use of wireless mobile communications by



▲ **FIGURE 4.** A police officer in the field can submit a "restricted zone" by using mobile GIS and GPS.

field-based personnel. Monitoring the progress of a fire, the extent of a flood, changes in transborder routes of travel, or shifts in border apprehensions measured against a common spatial reference (such as a satellite image) are crucial for effective emergency response and homeland security operations.

Allocation, deployment, and management of response resources depend on timely information conveyed via a common spatial reference. Knowledge of situational details at specific locations and



▲ **FIGURE 5.** A hierarchical architecture for GIS data portals. [[what does "register" mean in this figure?]]

the broad perspective across the whole area of interest is best achieved by integrating site-specific field reports through the BSDSS and disseminating deployment and response directives to front-line decision makers and field operatives. Satellite imagery provides the spatial context and geographic references upon which field location and situation information is coded via wireless mobile communications, providing the tactical status for decision making.

Learning from Disasters

The tragic results of the Southern California wildfires in 2003 and Hurricane Katrina in 2005 demonstrated the importance of a spatial decision support system for homeland security. Among the first demands made on relief agencies after those events were requests for satellite imagery, GIS maps, and wireless communications. Successful implementation of such systems in a spatial decision support service can save thousands of lives during a natural disaster or terrorist attack. Our research team used the case of Hurricane Katrina to re-examine our prototype system, and we concluded the following:

1. The service framework should include multiple data archive centers located in different places. For example, a San Diego data portal should have a backup data archive center located somewhere far from the city. In the case of large-scale disasters (earthquakes or hurricanes), local information infrastructures might be damaged or lost. With the remote backup centers, the rescue teams and the recovery tasks can restore this critical geospatial information quickly.

2. GIS data portals must be based on a regional focus concept, which means a nationwide GIS data portal might not be suitable for a local, regional emergency response. We need to define an appropriate regional scale for the homeland security system. Regional GIS data portals, such as those for the San Diego and Los Angeles regions, should be linked to the California state GIS data portal. Each state portal will be linked to a national GIS data portal (like Geospatial One-Stop, http://geodata.gov). Figure 5 illustrates an ideal hierarchical GIS data portal framework for a homeland security SDSS.

3. The BSDSS should have a clear procedure for data update processes. Most GIS data portals include some outdated information, which could jeopardize the use of geospatial information in emergency response and recovery. This outdated information needs to be marked and updated systematically.

4. Users should have varying levels of access privileges to the Web-based BSDSS. The general public might be able to access basic information and maps regarding the rescue efforts and the major damaged areas. First responders and decision makers will need to access more detailed and comprehensive information via the Web-based user interface. Locational privacy issues must be considered when distributing detailed geospatial information to different users as well.

5. The system needs to provide a scalable data security framework for both wired and wireless communications between the Web-based interface and the GIS data portal.

Strengthening Security

On January 17, 2006, Homeland Security Secretary Michael Chertoff announced plans to strengthen security at U.S. borders. "To strike the right balance between security and facilitation," said Chertoff, "we have to incorporate 21st century technology and innovation."

Indeed, we need to use state-of-the-art geospatial technology to provide a reliable, sustainable solution for maintaining homeland security. Innovative technologies (high-speed wireless communication, geospatial information services, Web-based mapping tools, Web services) can be applied to various tasks of homeland security and sharing critical information among decision makers and the public.

Although we cannot control natural disasters, we can greatly improve the way we plan for and respond to emergencies, whether natural or terrorist-induced, through the expanded use of geospatial technologies, satellite imagery, and wireless communications integrated into spatial decision support services developed at the local, regional, and national levels. These are some of the key 21st century technologies Secretary Chertoff refers to in his speech. How we prepare for and respond to emergencies is an indication of how seriously we take our homeland security obligations. The technology framework for the BSDSS can greatly improve our emergency response capabilities.

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Manufacturers

The Web-based BSDSS user interface developed in this project is based on a customized **ESRI** ArcIMS user interface. XML-based metadata files were compiled by ESRI ArcIMS Metadata Server. ◍