NCRST

NATIONAL CONSORTIUM ON REMOTE SENSING IN TRANSPORTATION

INFRASTRUCTURE

Spatial Information Technologies in Critical Infrastructure Protection

A Research Agenda In CIP

U.S. DEPARTMENT OF TRANSPORTATION
Research and Special Programs Administration

The National Consortia on Remote Sensing in Transportation are funded by the U.S. Department of Transportation, Research and Special Programs Administration, and NASA Earth Science Enterprise.

This research partnership involves four university consortia and a number of Technology Application Partners, working with transportation practitioners at the federal, state and local level in the U.S. and abroad.

Critical Infrastructure Protection (CIP) is a major focus of NCRST-Infrastructure. It is being addressed in a series of user consultations and specialist meetings, methodological research and publications. Participation of local agencies is essential to the success of this effort. For background on the program, updates to this document and additional NCRST resources, please visit our web site (below). Most consortium publications are available in digital form. You are free to reproduce them, giving credit as appropriate.

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FOREWORD

The National Consortium on Remote Sensing in Transportation—Infrastructure is examining the role of remote sensing and geospatial information technologies in Critical Infrastructure Protection (CIP), specifically in the identification and preservation of Critical Transportation Infrastructure (CTI). Activities planned for the coming year include

- compilation of materials and data of interest to local agencies,
- coordination of activities with CIP agencies,
- specialist meetings of CIP professionals, including private and public agencies, and academics.

In February 2002, NCRST-Infrastructure established a web-based public consultation to poll experts on high priority issues in CIP. This document is a first draft of a research agenda, based on input from the consultation, as well as other individual and group discussions.

We would like to thank, in particular:

- Donald F Cooke, Founder, Geographic Data Technology, Inc
- Michael W Everett, Manager, Homeland Defense, Wargaming, Education, & Training, Boeing-Autometric
- Edward F Granzow, Traffic/Transport. Modeling Tech Leader, Transport. Business Group, CH2MHill Engineers
- Cheng Liu, Center for Transportation Analysis, ORNL
- John P Murray, Chief, Information and Planning, FEMA
- Bruce A Ralston, Professor and Head, Department of Geography, University of Tennessee
- Steven John Tomisek, Senior Military Fellow, Research Directorate, Institute of National Strategic Studies
- Zdenka S Willis, Senior Military Fellow, National Strategic Gaming Center, National Defense University

Research projects reflecting some of the items in this agenda are already underway. Nevertheless the agenda will evolve with further input, and we continue to welcome contributions at the web site: *www.ncgia.ucsb.edu/ncrst/meetings/200202CIP*

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The Role of Geospatial Technology in Critical Transportation Infrastructure Protection: A Research Agenda

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Threats to the Nation's Critical Transportation Infrastructure

The transportation infrastructure of the United States, like every country in the world, has been vulnerable to attack, disruption, damage and destruction for many years. Although these disruptions have been caused principally by natural disasters such as floods, storms, fires or earthquakes, deliberate attacks on transportation facilities have occurred with increased frequency in the past 10 years [Everett]. The terrorist attacks of September 11, 2001 have created a new awareness of the critical role and vulnerability of transportation fleets and facilities.

Before this incident, no single disaster or attack affecting transportation facilities had resulted in significant national consequences. For example, although the 1994 Northridge earthquake in California, the 1993 Mississippi River flood and the 1992 Hurricane Andrew in Florida resulted in significant regional property damage and produced many casualties, none of these disasters seriously disrupted national travel or national economic activities. Travelers and shippers alike were able to exploit redundancies in the system while local transportation authorities quickly restored service in each of these areas. However, the experiences of September 11, 2001 and the concern over future attacks has given renewed emphasis to adopting better strategies for transportation (and other essential infrastructures) disaster preparedness, response, recovery and mitigation.

What is the Critical Transportation Infrastructure?

The United States maintains approximately 4 million miles of streets, roads and highways, over 580 thousand bridges, 150 thousand miles of railroads, over 5000 public airports, plus 1.3 million miles of gas pipeline and 180 thousand miles of oil pipelines [BTS]. While each of these facilities provides much-needed travel and economic links to local communities, the vast majority supports primarily local movements of persons and goods. Only a small subset of the entire transportation infrastructure can be considered of major national interest.

Although no universally agreed upon definition of or criteria for the Critical Transportation Infrastructure (CTI) exists, most observers would agree that the CTI is composed of those transportation facilities whose removal from service would significantly affect public safety, national security, economic activity or environmental quality. Some commentators suggest that only those facilities that are essential to national defense or global economic activity be designated as "critical." Any facility falling short of these measures can be labeled "important" [Everett]. In the absence of a formal CTI designator, federal, state and local officials have the latitude to designate CTI facilities of varying degrees of importance. That is, what is deemed critical to a particular state or city may not be critical from a national perspective and vice versa.

A related but distinct concept involves "transportation lifelines," transportation facilities providing essential accesses for emergency services to disaster sites and allowing for the evacuation of at-risk persons and property from those sites. Transportation lifelines are primarily local in nature and are defined by the location, type, and severity of the disaster and by the demographics and land use of the region in which the disaster occurs. Again, designated local and regional lifelines may not coincide with national ones.

Examples of Critical Transportation Infrastructure (CTI)

1. Major arterial highways and bridges comprising the National Highway System (NHS), including the Strategic Highway Network (STRAHNET) and National Intermodal Connectors.
2. International marine harbors, ports and airports.
3. Major railroads, including depots, terminals and stations.
4. Oil and natural gas pipelines.
5. Transportation Control Systems (e.g., air traffic control centers, national rail control centers) [Everett].

However, most of the threats, disaster management functions, information needs and technology opportunities presented in this discussion apply equally to critical facilities and to transportation lifelines. Moreover, since the requirements for defining and developing a comprehensive system of disaster are independent of the specific facilities designated, both critical facilities and transportation lifelines will be referred to as critical transportation infrastructure (CTI).

Threats to the Critical Transportation Infrastructure (CTI)

1. Natural Disasters
   a. Fires
   b. Floods
   c. Storms
   d. Earthquakes
2. Human Caused Disasters
   a. HAZMAT spills and releases
   b. Major traffic crashes
3. Social, Criminal and Terrorist Activities
   a. Vandalism
   b. Sabotage
   c. Civil unrest/riots/strikes
   d. Attacks using chemical, biological, nuclear or explosive weapons
4. Other
   a. Deferred maintenance and neglect
   b. Energy and material shortages

Threats to the Critical Transportation Infrastructure

In general, a threat to the CTI can be any event, incident or condition that has the potential for removing a portion of the CTI or severely degrading its performance for a significant amount of time. Note that the concept of threat is distinct from the risk to the CTI, which is a more complex combination of threat, exposure (the likelihood of the threat affecting a particular facility) and consequence (the direct and indirect costs of a successful threat). Threats can come from natural causes, as a by-product of human activities or from deliberate actions undertaken for criminal or terrorist purposes.

Because of its ubiquitous presence in our society, every natural, accidental, criminal or other disruptive event, whether targeted at a transportation facility or not, will have some effect on travel and transportation. Conversely, any attack or incident targeted at critical transportation facilities will likely affect other critical infrastructures (e.g., the electric power or communication distribution systems, food or water supplies, government services, fuel supply). Accounting for these interdependencies adds much more complexity to an already daunting task facing the Disaster Manager. These critical interdependencies may preclude focusing exclusively on the CTI.

Critical Transportation Infrastructure Protection (CTIP)

In some sense, the term "Critical Infrastructure Protection" is a misnomer. Since disasters are, from the point of view of the CTI, inherently random in nature, no critical transportation component can be "protected" (i.e., made secure from any damage to the CTI, persons and property). No fail-safe methods, technologies or approaches exist that can eliminate all conceivable risk to the CTI. Earthquakes will still occur, accidents will still happen and dedicated terrorists will still succeed. Even with continuous monitoring and surveillance, threat interdiction remains an elusive and unrealistic goal. Additionally, because transportation facilities are intended to provide maximum access, no realistic strategy can eliminate the facility's risk exposure.

Moreover, trying to identify all possible exposures of all possible threat events across all critical components and forecasting all possible consequences is an impossible task. Each piece of the CTI has unique physical and performance characteristics, managed by semi-autonomous agencies; each threat to the critical transportation infrastructure poses unique risks and consequences to individual components of the CTI.

Although "protection" of the CTI remains an impossible ambition, Disaster Managers can adopt competent strategies for disaster management to effectively reduce the impact of disasters [Banger]. These strategies typically include pre-disaster preparedness, emergency response, disaster recovery and long-term mitigation activities. The goals of Critical Infrastructure Protection are more realistically set to minimize the consequences of a disaster through timely event notification, information-driven responses, prepared first responders and citizens and pre-planned and rehearsed contingency activities.

Federal, state and local officials have different roles in disaster response, homeland security and terrorism response situations. In natural disaster events, the federal government is responsible for early detection and forecasting activities. Federal agencies including FEMA, USACE and USDOT assist state and local governments in response and recovery operations. For homeland security and terrorist threats, the federal government is responsible for the detection and prevention of terrorist attacks, while state and local groups carry out preparedness and response activities [ISPFS]. In order to be effective, disaster planning, response, recovery and mitigation activities must be fully integrated into "normal" planning and operational activities conducted in an inter-agency climate of cooperation and coordination. Disaster management represents a set of interdependent problems that require intensive communication and coordination among organizations and jurisdictions to reduce risk and losses [WGPR].

Sample CTI Disaster Information Needs

1. CTI baseline inventory and condition data.
2. Remediation and contingency plans.
3. First responder data including who, what, where of the current situation to increase response efficiency and reduce property and casualty losses.
4. Current and predicted information about the specific event and its consequences.
5. Current and predicted at-risk element data including persons, property and other infra-structure.
6. Simple, clear, unambiguous information on the impact of the incident. That means preparing reports and maps which are legible, limited to essential data, and easy to understand [Murray].
7. Vulnerability analysis of intermodal transpor-tation networks and other critical infrastruc-ture [Tomisek].
8. Identification of 'danger areas' at the confluence of intermodal transportation means and critical infrastructure such as nuclear power generation facilities, chemical plants, etc [Tomisek].
9. Socioeconomic and demographic impacts. Where are people displaced and in what numbers? Where should displaced people go? [ISPFS]
10. Access to impacted areas [ISPFS].
11. Thermal activity and displacement of the debris field [ISPFS].

The experience accumulated from the disasters of the past few years suggest that having the right information, in the right format, at the right time in the hands of the right people significantly reduces the consequences of disasters and accelerates the recovery process.

Disaster Management Information Needs

Understanding the potential risks and impacts of natural disasters requires sound knowledge concerning the features of the landscape, the patterns of human development, and a scientific understanding of natural disasters (wildfire, earthquakes, landslides, volcanoes, sea storms, avalanches, rapidly changing ocean conditions, and flooding) [WGPR]. Human-caused disasters require similar understanding of the geographic context surrounding the incident and additional scientific information specific to the disaster type (e.g., toxic plume formation and dispersal).

Previous experience has shown that waiting until a disaster occurs to develop the baseline data, impact models, institutional interoperability strategies and communication protocols is an almost impossible task. This implies that transportation officials must identify and develop a core set of common data beforehand to be able to respond effectively. This also implies that disaster preparedness exercises simulating event response activities are critical to uncover and redress information needs, data and technical incompatibilities, institutional barriers and so on.

Although each disaster is unique, common core information needs can be identified for a variety of CTI scenarios. More importantly, common approaches to quickly acquire additional data can be devised and tested during preparedness drills.

The experience accumulated from the disasters of the past few years suggest that having the right information, in the right format, at the right time in the hands of the right people significantly reduces the consequences of disasters and accelerates the recovery process.

The Role of Geospatial Technology in Critical Transportation Infrastructure Protection

Remote Sensing Technology

Remote sensing data — primarily satellite and/or airborne imagery (RS) — combined with Geographic Information System (GIS) technologies are critical components in federal, state, and local disaster services preparedness, detection, response, and recovery plans. These agencies have found RS/GIS invaluable in planning strategic responses, developing tactical response plans, formulating and carrying out mitigation programs, and analyzing incident data for training and policy-making processes [WGPA]. Remote Sensing and GIS make for quick and accurate map generation; and provide analytical capabilities not possible without these technologies during response and recovery operations as well [Bruzewicz] [ISPFS].

A new generation of public and commercial remote sensing platforms containing much higher spatial and spectral resolution sensors has been deployed over the past five years. It is now possible to purchase wide-area, high-resolution satellite imagery that rivals intelligence data of a generation ago. While the details of these technologies are beyond the scope of this paper, trends toward lower cost and higher quality RS data are expected to continue for the near future.

Of course, the ultimate question revolves around the question of adequacy. In other words, is RS/GIS data better (e.g., cheaper, more timely, more accurate) than other data sources in satisfying the information needs discussed earlier? This is a trick question since in many cases there are no other alternatives. Disaster sites may be inaccessible to first responders and recovery forces due to obstruction, hazardous conditions or their remote location, making on-the-ground observations difficult or impossible. Additionally, significant events (e.g., earthquakes, tornadoes, explosions, and fires) may have significantly changed the area making earlier RS/GIS data obsolete. In these situations, RS technologies may be the only source of up-to-date information.

Remote Sensing Data Types

1. Satellite Platforms
    a. Commercial, high resolution satellite imagery, including multi-spectral and hyperspectral data
2. Aerial platforms (manned and unmanned)
    a. high-resolution color and BW photography
    b. hyperspectral imagery (e.g., AVIRIS)
    c. Light Detection and Ranging (LIDAR)
3. Fixed, Ground-based Sensors
    a. Surveillance CCT and video

Examples of CTI Damage Detected using Remote Sensing Data

1. Obstructed highways, roads, streets and rail lines
    a. Trees, poles, wires
    b. Debris
2. Washed out and flooded highways, roads, streets and rail lines
3. Disrupted road, track and bridge surfaces
4. Collapsed or damaged elevated and subway structures
5. Oil and gas pipeline leaks and breaches

Source: UWDMC

Remote Sensing Benefits

The accumulated experiences of many governmental, academic and private organizations worldwide over the past 20 years of natural disaster forecasting, monitoring and management unambiguously indicates the value of RS/GIS. Although human-caused disasters are relatively new phenomena, many of the lessons learned are directly applicable to disasters affecting the CTI. There is no reason to believe that the benefits of RS/GIS would not apply to CTI oriented events as well. These benefits include:

1. Low cost, wide area "at-a-distance" data
2. Rich, interoperable, multi-purpose data
3. Potential inputs into disaster simulation models [Liu]
4. Potential inputs into threat prediction models
5. Identification of critical infrastructure elements [Granzow]
6. Rapid change detection data
7. Backdrop for other spatial data and analysis products [Bruzewicz]
8. Visualization for public information and policy briefings [Bruzewicz]

GIS Benefits

Geospatial data and technology has been used for disaster and emergency management activities worldwide for many years. In the United States, FEMA, NASA USACE, DOE, numerous other Federal, State, and local agencies have active geospatial based disaster and emergency management systems. Additionally, many universities offer professional development courses and workshops on the application of geospatial technology to Disaster and Emergency Management [UWCDM]. Perhaps the starkest testimony regarding the value or GIS was realized in the immediate aftermath of the September 11 attacks where over 5000 maps and other geospatial products were produced. This experience and others have highlighted the following benefits of using GIS in the Disaster Management Cycle.

1. Disasters typically engage many, if not most, governmental agencies with interests in the affected area. GIS provides a way for agencies to share operational data and to integrate event data using common locations. In many cases, positional data regarding debris and damage is collected using GPS.
2. Most of the information requirements for disaster are spatial and can be presented on maps. Geospatial technologies can rapidly combine map data with RS and on-site data creating special-purpose information products.
3. Proximity analysis is a standard GIS function. This capability is used for in disaster planning preparedness, response and recovery operations to determine how features are related to each other. For example, to determine how many people live in the path of a wildfire, where the evacuation routes are, where fire fighting resources are positioned relative to the fire, what other infrastructures may be threatened by the fire and so on.
4. Network analysis (e.g., shortest path) is also a standard GIS function and is used to plan and manage evacuations, assess the effects on the loss of one or more transportation links, dispatch of emergency personnel and equipment.
5. Automated Vehicle Locators (AVL) can be used to locate and track in real-time, the positions of first responder units, many times in conjunction with Computer Aided Dispatch (CAD) systems.
6. Geospatial data bases are the source of data used in various disaster modeling and simulation packages. Conversely, GIS display and mapping tools can be used to present modeling and simulation results.

Issues limiting the use of RS/GIS in disaster management

Unfortunately, there is a real possibility that these benefits may go unrealized because of existing barriers to widespread acceptance and use. Satellites are not always ideally placed at the time of the disaster. In some cases, core data and systems are unavailable. In others, Disaster Managers are unaware of the existence and utility of RS/GIS. If the data cannot be easily understood, processed, integrated and presented in a timely manner, CTI Disaster Managers will find other alternatives. Moreover, if society prevents CTI Disaster Managers from acquiring RS/GIS data for public policy reasons (e.g., cost, privacy, security), the benefits will also remain illusory. The following issues, if not resolved, may effectively limit the diffusion of RS data and technology into the CTI community.

1. Useful data may not be available due to sampling limitations (e.g., periodicity, sensor type, cost).
2. Information latency or the time it takes from sampling to delivering information products is unacceptable.
3. Transforming RS data into useful information often requires expertise that is not readily accessible [ISPFS].
4. Well understood and pre-planned information needs are not available.
5. Citizens and businesses have privacy concerns concerning high-resolution data.
6. CTI information is highly sensitive and may create security and access restrictions.
7. RS/GIS is a high-tech solution for a low-tech community, often resistant to such approaches.
8. Lack of interoperability between different data sets [ISPFS].
9. Data collection can be adversely affected by time of day, weather and cloud cover [ISPFS].
10. Difficulty with interagency communication, cooperation and coordination including technology incompatibilities [ISPFS].

Perhaps the largest issues limiting the widespread adoption of RS/GIS tools and data arise from institutional and organizational factors. There is a wide gap between the geospatial, first responder and transportation communities because of differing missions, perspectives and priorities. For example, new disaster oriented tools and data must compete for scarce resources in transportation organizations whose higher priority is routine construction and maintenance. Conversely, first responders are much more interested in tactical mobile technologies such as cell phones, than in geospatial ones, which are more strategic. And finally, the geospatial profession is focused on spatial analysis often without sufficient understanding of the problem domains at which their tools are targeted.

The challenge then, is to envelop critical CTIP processes, data and technology into the ongoing operational missions of these organizations and also to create new understandings promoting shared interests in the CTI.

Potential Role of the National Consortia for Remote Sensing in Transportation (NCRST)

Although the NCRST consortia have been conducting various basic and applied research projects for the past two years, there has not been an emphasis on CTI. However, the basic experience gained in RS/GIS technology and transportation issues positions them to refocus on CTI issues.

The following project concepts are proposed to direct the attention of NCRST participants and to provide a foundation for commercial firms in product development.

Coordination, Cooperation and Support Program

1. Prototype RS/GIS applications for disaster management.
2. Expose the Transportation, Disaster Management and First Responder communities to RS/GIS technology and techniques common to all three groups.
3. Develop information use scenarios, including roles, responsibilities and information flows, incorporating the role of new technologies, e.g. GPS, wireless communication devices.
4. Develop cost and benefit models, and demonstration projects in cooperation with high profile jurisdictions (e.g. Los Angeles).

Basic and Applied Research Program

1. Develop a theoretical framework linking disaster type with specific information needs and RS data sources encompassing the Disaster Management Functional Cycle (i.e., planning, response, recovery and mitigation).
2. Develop a spatial framework, a systematic methodology and statistical measures for analysis of risk and vulnerability of the CTI [Husdal].
3. Develop methods and standards for communicating and visualizing risk and vulnerability of the CTI [Husdal].
4. Develop a spatial framework, a systematic methodology and statistical measures for the determination of disaster consequences.
5. Develop change detection methods and tracking mechanisms for specific disaster types (e.g., terrorist attack).
6. Develop RS/GIS based models of critical infrastructure interdependencies.
7. Develop rapid deployment RS/GIS data collection technologies such as fixed tethered balloons and unmanned aerial vehicles (UAVs) to monitor rapidly changing disaster conditions (e.g., spatial extent of disaster area, toxic plumes, fire propagation, flooding, evacuations and population displacements).

Concluding Perspectives

The unfortunate short-term reality facing the CTI is that the country cannot protect all of its critical transportation facilities all of the time. A more realistic although still challenging goal, as expressed by Presidential Decision Directive 63: Critical Infrastructure Protection, is to ensure that disruptions are "brief, infrequent, manageable, geographically isolated, and minimally detrimental" to national welfare. This goal needs to be met cooperatively by Federal, State and local agencies working in concert with the private sector.

Having the right information and more importantly, getting it to the right people is an essential strategy in achieving this goal. Information is key, and geospatial information particularly so. However, we cannot always predict specific information needs in advance. One idealistic approach to this dilemma is to try to collect and share all possible information on everything, and to update it constantly. However, the realities of tight budgets, competing priorities and jurisdictional barriers preclude this.

A more achievable approach is to define and maintain a core set of geospatial information, defined and managed cooperatively and augmented with contingency plans allowing for the rapid acquisition of new information as necessary. Geospatial information technologies allow Homeland Security officials to better assess vulnerability, to allocate mitigation resources based on vulnerability, to rapidly deploy emergency forces to reconstitute transportation services and to communicate effectively with each other, the media and other interested persons. These essential objectives cannot be achieved without significant investments in data, technology and training activities. Officials coping with rapidly unfolding emergencies, disasters and attacks do not have time to gather new baseline data or to deploy untested technology.

Proper management of the nation's considerable Homeland Security budget demands that we invest a small amount now to determine which data and technologies will be of the most benefit in the future. Preparedness depends on having the right technical resources and, more crucially, on having Disaster Management professionals aware of these tools, knowledgeable in their use and convinced of their value. Again, relatively small investments now in establishing operational ties between transportation, first responder and technology organizations are a prudent and necessary step.

Critical Infrastructure Protection

1. Assess CTI vulnerabilities to cyber or physical attacks.
2. Develop plans to eliminate significant vulnerabilities.
3. Propose systems for identifying and preventing attempted major attacks.
4. Develop plans for alerting, containing and rebuffing attacks in progress.
5. Rapidly reconstitute minimum essential capabilities in the aftermath of an attack.

PDD 63

The underlying principle of the CIP research agenda is to foster a new partnership between the geospatial and disaster communities. The NCRST Consortia are uniquely positioned to provide the bridge spanning the technology divide between RS/GIS tools and their ultimate users.

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