REMOTE SENSING AND TRANSPORTATION SECURITY

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ABSTRACT

Transportation lifelines are a vital element in maintaining U.S. security from terrorist attack. They are also vulnerable to attack and disruption. As officials have discovered since September 11, 2001, protecting and preserving the extensive U.S. transportation networks against terrorist attacks remains a daunting task. Fortunately, today's powerful geospatial tools, especially remote sensing, GPS, and GIS, can assist in this crucial effort.

The National Consortium on Safety, Hazards, and Disaster Assessment (NCRST-H) within the National Consortia For Remote Sensing in Transportation is uniquely positioned to assist security officials in applying these tools to protecting critical infrastructure. Many of the methodologies and technologies that have been identified or developed by this consortium over the past two years of research are ideal for responding to the challenge of improving the safety and security of transportation lifelines.

In order to understand the full scope of the challenge and to chart an appropriately focused response, the consortium convened a workshop focused on exploring how and where remote sensing and related geospatial technologies can assist in achieving a high level of U.S. transportation security. This paper reports on the findings and recommendations of this workshop. In particular, it explores the benefits and limitations of current remote sensing capabilities and data policies for addressing transportation security needs.

INTRODUCTION

Remote sensing technologies, along with related geospatial technologies, contribute powerful tools for preserving and protecting the nation's critical infrastructure from terrorist attack. In March 2002, the Safety, Hazards, and Disaster Assessments Consortium (NCRST-H) of the National Consortia on Remote Sensing in Transportation (NCRST) convened a workshop designed to explore how remote sensing can most effectively assist federal, state, and local transportation officials meet the threat of terrorist activities directed at transportation facilities. This paper reports on that workshop.

The nation's transportation system is extensive, complex, and critical to maintaining the U.S. economy and citizen mobility. Major disruptions to any part of the system, whether through direct attack, or through strikes on co-located facilities, would severely affect the nation. Table 1 shows the estimated extent and use of the U.S. transportation system. Formulating potential threat scenarios and assessing the impacts of these scenarios lie at the core of protecting the infrastructure and its users; and probably will require new approaches to estimating vulnerabilities. Remote sensing data and methods can help reduce the vulnerabilities of the U.S. transportation system and lessen the risk of attack.

Table 1. Estimated Extent of America's Transportation System		
System	**Infrastructure**	**Use**
210 million vehicles	4 million miles of road 500,000 bridges (1/3 of 127,000 urban bridges serve as major arterials	4 trillion passenger-miles 920 billion freight ton-miles
1.2 million railroad cars 250 intercity Amtrak trains	150,000 track miles	20 million passenger miles 1.3 trillion ton-miles
175,000 aircraft	5,500 public use airports	403 million passenger miles
12 million watercraft	25,000 miles of waterways	600 billion ton-miles of oil
Pipelines	1.6 million miles	19 trillion cu.ft. of gas
Multimodal transport	Freighters, trucks, railroad cars	5 million containers each year through major U.S. ports

Source: Department of Transportation Research and Special Projects Administration

Remote sensing from space offers transportation planners and safety experts a broad synoptic view with the ability to detect changes in surface features quickly and routinely. Sensors mounted on aircraft allow analysts to examine areas in great detail from below the clouds, and ground-based systems make possible the detailed observation of events in real time. Each of these spheres of remote sensing technology hold benefits for transportation, and in particular, for the security of the nation's complex transportation networks (Box A).

Box A. Remote Sensing in Support of Critical Transportation Infrastructure Protection

Remote sensing technologies include both imaging sensors and non-imaging sensors (Box A). Remote sensing and other geospatial information technologies provide a vital spatial and temporal foundation for all phases of the U.S. response to terrorist threats:

- **Detection:** New digital techniques allow for "data mining," the rapid spatial and temporal comparison of both imaging and non-imaging sensor data, to craft effective and efficient threat analysis. By linking and analyzing information related both temporally and spatially, it is possible to detect potential threat patterns, distinguish likely terrorist targets, and prepare appropriate responses.
- **Preparedness:** Emergency response planners require current and accurate geospatial information that is readily available in interoperable databases. Up-to-date remotely sensed imagery aids planners in responding to terrorist attacks, natural disasters, and other emergencies. Emergency responders should have available current, high resolution imagery of every major facility that could be a potential terrorist target in order to assist emergency crews in case of attack. Such imagery will also assist in case of natural disaster.
- **Prevention:** Patterns discovered through analysis of geospatial information can provide a means to respond to terrorist threats and deter attacks. This information, when fused with additional information about borders, waters, and airspace, can help disrupt and interdict attacks.
- **Protection:** Remotely sensed data are particularly important for analyzing the vulnerabilities of critical infrastructures. Decision support technologies such as scene visualization and incident simulation assist in anticipating the direction and form of potential attacks and in designing protective tactics and strategies. Such technologies make it possible to view the interaction of transportation lifelines with other geographically related critical infrastructure, such as power plants, population centers, and financial centers.
- **Response and Recovery:** Effective response to natural and human-induced disasters requires rapid analysis of imagery and other sensor data acquired both before and after the event. Such information will enable emergency response services to clear blocked transportation routes rapidly and to reroute traffic efficiently. Likewise, recovery efforts depend on the acquisition and analysis of timely imagery and other remotely sensed data that might indicate the presence of toxic or noxious chemicals. Compatible, interoperable geospatial databases containing base information that can be rapidly updated will assist in saving lives and reducing costs.

This workshop, composed of experts in transportation, remote sensing, and other geospatial technologies, was designed to explore a wide range of issues related to the protection of U.S. critical transportation infrastructure. The workshop not only examined potential applications for remote sensing technologies in transportation security but also identified some of the major barriers to effective utilization of such technologies. Finally, it set the stage for potential later workshops focused on identifying research agendas for specific elements of the nation's transportation infrastructure.

POTENTIAL OF IMAGE & SENSOR DATA FOR IMPROVING LIFELINE SECURITY

Remote sensing technologies, together with GIS and position, navigation, and timing systems, can play a significant role in improving the Nation's transportation security and protecting critical infrastructure. Remote sensing from space combines a broad synoptic view with the ability to detect changes in surface features quickly and routinely. Remote sensing from aircraft allows analysts to examine areas in great detail from below the clouds, and ground-based systems make possible the close-in observation of events in real time. Each of these spheres of remote sensing technology hold benefits for use in transportation, and in particular, for the security of the Nation's complex transportation networks.

Examples of the use of remotely sensed data to support transportation security include the ability to:

- Develop accurate digital terrain models and 3-D surface features as a means for modeling landforms along rights-of-way;
- Visualize terrain from different perspectives, with the potential for developing threat cones and viewsheds;
- Classify vegetation types along transportation lifelines to assess concealment of possible terrorist activities;
- Detect, classify, and analyze temporal and spatial changes in surface features;
- Identify facilities where topography or identifiable hazards (e.g., nuclear, chemical, fuel facilities), place communities at risk;
- Analyze environmental factors quickly and effectively;
- Merge real-time sensor output (video, bio-chemical sensors) with archived geospatial data;
- Identify, characterize, and analyze a wide variety of risks to transportation networks through a gradual program of gathering image intelligence along rights-of-way;
- Create detailed maps to assist in response to an area that has suffered attack.

THE VALUE OF REMOTE SENSING FOR CRITICAL INFRASTRUCTURE PROTECTION

Imaging Sensors

Scalability. Literally hundreds of civil applications make use of remotely sensed imagery in a variety of analytical products. A multiplicity of image types has evolved to address specific applications, and many can also be used for transportation lifeline protection, if integrated into shareable databases. Imagery can be acquired across many scales and corrected geospatially to fit agency-specific map projections. For incident management, planners already have tools available to them for integrating coarse with fine resolution satellite views, and with more detailed high, medium, and low altitude aerial data sets from LiDAR and RADAR systems. The large number of demonstrated applications meeting industry and government standards should be systematically reviewed for their use in transportation lifeline security.

Spatial Relationships, Vulnerability, and Up-Dating. Urban planners have traditionally recognized tone, texture, size, shape, and spatial arrangement as image attributes for analyzing landscape features. For transportation lifelines, most traditional applications have focused on right-of-way planning, engineering cut and fill measurements, feature identification, and land use classifications for map-making purposes. Just as traditionally imagery has generally not been archived and in most cases has been destroyed after these immediate uses were achieved. Yet these images and older data sets contain much intelligence.

Where image archives can be retrieved, they represent a resource for measuring the rates and directions of lifeline infrastructure growth. These images also show changing spatial relationships among urban features that might not be considered by planners until the post-recovery phase of an incident (for example, obstructions like fences between buildings and roads that would prevent rapid evacuations, or road designs that have changed from two-lanes to four-lanes with a median). Most important, time series imagery is scalable from the local level for which it was acquired, to smaller scales for which it might be needed for managing future incidents. In short, lifeline vulnerabilities develop over time and can only be efficiently catalogued, referenced, and assessed by examining the history of imagery for an area. Imagery should be updated routinely and especially vulnerable areas should be imaged in high resolution.

Data Mining. For the more sophisticated needs of the 21st Century, transportation planners should recognize that time-series digital images represent a data archive that can be used to answer questions not yet posed. They are essential for responding quickly and efficiently to an emergency. Today's technology allows image archives (also called image pools) to be highly compressed for digital storage, and for them to be queried constantly for phenomena that are "out of the ordinary." Data mining algorithms can burrow through a set of chronologically arranged images (pixel-by-pixel if necessary), and can be programmed to detect specific features, relationships, or trends that "trigger" an event or suggest locations where field personnel might visit. To take an example from the environmental realm, the ability to detect the future onset of El Niño episodes is enhanced by daily, seasonal, and annual data mining queries of sea surface temperatures in the equatorial Pacific. Future "episodes" of El Niño are being predicted on the basis of past occurrences melded with our growing understanding of El Niño's triggering mechanisms. Mathematical techniques such as rule-based systems and fuzzy logic help data mining algorithms to interpret the intelligence contained in the images. We are, in effect, "teasing" information out of data in much the same way an accountant finds aberrant numbers in a column of numbers.

Visualization. Exciting opportunities abound for visualizing aspects of transportation lifelines. Visualization usually involves integrating digital elevation models (derived from either stereo photographs, LiDAR, or Synthetic Aperture Radar) with imagery and other geospatial data. Airport glide path obstructions, intermodal facilities, underpasses, overpasses, flyovers, bridges, pipelines, international border crossings, port facilities, and railroad crossings are all candidates for 3-D visualizations and virtual reality, once the proper data structure and environment have been established. For several years, military pilots have trained for missions in new settings by "flying over" an area virtually using imagery gathered by satellite, subsequently draped over a digital elevation model of the area, and tilted to simulate the perspective from a cockpit. For lifeline security planning, this capability alone may help thwart or mitigate incidents involving shipments of hazardous materials, or interdict possible terrorist activities, by showing swat teams the entire incident area before deploying human resources (for example, height of roadside embankments, locations and sizes of culverts, viewsheds, and related incident attributes). Visualizations can, of course, be created without image backdrops, and for some needs these may be desirable; but for realistic, real-time, incident management, the actual ground area needs to be modeled.

Detecting Subtle Landscape Changes. Change detection over time is one of the major uses of archived imagery. Two change detection applications that have widespread appeal for lifeline safety and proven adaptability for incident management are detection of thermal patterns and subsidence zones. The former represents mature technology in use for the last 30 years or more, particularly in fire mapping. Hot spots at WTC ground zero were mapped in the days after September 11 and were used in recovery operations to direct ground crew operations. These hot spots are detectable in the 3-5µm spectrum because they are much hotter than their surroundings. For detecting specific phenomena in the ambient landscape, a sensor operating in the 8-14µm spectrum could be used to detect such phenomena as ship wakes, contrails, and cool spots left by parked vehicles, all of which represent information useful for counter terrorism or interdicting illegal activities.

Detecting subsidence patterns is a less mature technology, but one having proven transportation lifeline safety applications that should adapt well to incident management and planning. Subsidence occurs frequently in areas where ground water withdrawals exceed recharge on a seasonal or annual cycle. Subsidence is also a characteristic of active earthquake zones. Interferograms produced from time series of synthetic aperture radar phase data are capable of detecting subsidence on the order of centimeters; enough to endanger pipelines, rail lines, and highways, and enough to damage bridges and make on- and off-ramp speeds unsafe.

Monitoring Consequences of Incidents. Recovery from damaging incidents, natural or otherwise, is an ongoing element of security and public safety planning. Relief and health officials need to know where the transportation lifelines have been disrupted, which avenues are still available for evacuation, or where evacuees are beginning to congregate. Image analysis within a GIS architecture can assist recovery crews to develop this information. In some cases, the imagery alone provides adequate information to inaugurate relief activities. NOAA's geostationary or polar-orbiting satellite imagery can be used for monitoring unusual smoke plumes. Knowing the extent of the plume, and direction of drift, may help in rerouting rail, bus, truck, even aircraft (probably more low flying aircraft than those at cruising altitude), away from the area. The NOAA geostationary satellites can serve as a good platform for this since they provide constant viewing of the Western Hemisphere on an operational basis.

Non-Imaging Sensors

Detect Precise Object Locations at a Precise Time. GPS is a well-known and widely used technology for pinpointing the locations of objects on Earth and for navigating between points. A companion capability develops data from an inertial measurement unit (IMU) to translate platform location to precise object locations on the ground. In day-to-day office environments, object locations can be derived adequately from using imagery analyzed by soft-copy photogrammetric techniques and integrated with traditional GIS data sets; but incident management may require the determination of spot locations, or the ability to follow objects moving along lifelines. These surveillance capabilities are possible and need to be incorporated into the stable of operational techniques employed at local and regional levels. Because the GPS satellites also broadcast precise time signals, they are highly useful for recording the precise time of events, which may be critical in certain applications.

Detect Biological and Chemical Agents. Some remote sensors are designed to detect and analyze the chemical constituents of gases emanating from objects. Recently developed technologies also include techniques capable of detecting trace amounts of gases (in the parts per million range, and finer). These are non-imaging multispectral sensors that can be "tuned" to find specific chemical compounds in a complex atmosphere of numerous gases. Sometimes called "sniffers," such devices could be deployed over multimodal transfer points and international border crossings to identify suspicious containers, railroad cars, or trucks. Harbor facilities might also monitor movements of ships and other watercraft by installing sniffers on uninhabited aerial vehicles (UAVs) that can stay aloft for anywhere from a few hours to several days or weeks. Within territorial waters, these devices might also be mounted on helicopters for monitoring ships well before they enter harbor areas.

Provide local weather conditions. The data collection systems onboard the NOAA geostationary and polar orbiting satellites can also be used to prepare for, and respond to, terrorist attacks. These systems can relay critical environmental data from a site back to an analysis facility. Such was done as part of the response to the World Trade Center event. The Environmental Protection Agency (EPA) deployed sensors around the area to collect air quality measurements. The data were then relayed back to Washington, DC via the GOES Data Collection System for analysis of dangerous or toxic substances. In the future, sensors could be deployed at specified facilities, so that if a chemical or radiological event were to occur, the data would be continually reported. If a chemical explosion occurred at a port or airport, these sensors would automatically send information back and responders would know what was released at what concentrations for whatever the sensor was designed to measure. Such data, matched with other geospatially referenced information would help to recognize area impacts, so that with additional information decisions for public safety can be made.

FINDINGS

The workshop arrived at four groups of "findings," or conclusions:

Finding One: Local, state, and federal responses to the events of September 11, 2001, illustrate the need to develop more effective coordination among emergency response agencies in their use of geospatial data and information. Many geospatial tools already exist but cannot be used effectively because of weak or non-existent mechanisms for sharing critical information.

Workshop participants concluded that although many of the necessary geospatial tools were already in place, their utility was limited in large part because of structural or institutional barriers. Accordingly, the nation needs new institutional policies to support improved transportation security and coordinated emergency response. Meaningful progress toward preparing the nation for both prevention and response to attacks on elements of the nation's transportation networks requires the harmonized effort of agencies across the federal government: among federal, state and local governments, as well as among government and private sector geospatial data providers and analysts.

One of the strengths of a geospatial information systems approach is that one comprehensive database for a region can support many different applications. As a result, the geospatial data and information developed for other uses can also support improvements in transportation security.

Finding Two: Remote sensing technologies would be a major asset in identifying and mitigating transportation security weaknesses throughout the United States.

The U.S. transportation system as it now exists possesses many vulnerabilities that could have been avoided with careful advanced planning and attention to security. Remote sensing can assist both retrospective analysis and future planning. Future planning should emphasize the decentralization of facilities and the redundancy of their functions. In this way individual facilities, whether pipeline corridors or roadway conurbations, are reduced in their critical role in the network and their attractiveness as targets.

Finding Three: The United States needs to develop an accessible geospatial infrastructure corresponding to, and compatible with, the nation's transportation infrastructure. The resulting geospatial information infrastructure should reflect all elements of the transportation infrastructure, and include detailed information on location, structure, and condition. This information should be broadly accessible to transportation and security professionals.

Improving the interoperability of transportation geospatial databases should be a high level priority. Currently, in attempting to use transportation databases, users often experience limitations on availability, integration, and use of geospatial data and technologies for transportation security. Information regarding the nation's transportation infrastructure is widely dispersed in a variety of databases, in a multiplicity of formats and software. Many of these databases are not readily interoperable, making the task of using them especially difficult in times of crisis. Compounding this concern is a lack of suitably interoperable technical standards, both for data sharing and for operating hardware and software.

The Federal Geographic Data Committee (FGDC) has published standards that, if adopted by state and local users, would resolve concerns regarding technical interoperability. However, policy restrictions on access to critical data and information in time of emergency can be more serious impediments to interoperability.

Finding Four: Research, development, testing, and evaluation should focus on creating products specifically designed to fit transportation security needs for all aspects of the terrorist challenge.

All elements of the terrorist threat to the nation's critical transportation infrastructure need to be met; remote sensing and other geospatial tools should be developed to the fullest extent of their potential. In addition, first responders and transportation planners need to be much more aware of the capabilities of remote sensing imagery products to supply critical information necessary for managing emergencies of all types. Sensor data, whether from imaging or non-imaging sensors, should be integrated with existing geospatial databases.

RECOMMENDATIONS

1. **The Federal Emergency Management Agency, working with the U.S. Department of Transportation, the U.S. Geological Survey, and the U.S. Army Corps of Engineers should develop guidelines for federal, state, and local entities to share transportation-related geospatial information in support of coordinated planning and response to terrorist threats.** Effective planning for, and response to, terrorist attacks will require the various affected agencies at all levels of government to be able to share critical information quickly and efficiently. Current data sharing policies at all levels often impede effective information sharing.

2. **The U.S. Department of Transportation should lead an effort to develop an accessible geospatial transportation information infrastructure corresponding to, and compatible with, the nation's transportation infrastructure.** Each element of the transportation infrastructure can be characterized in a geospatial database. The totality of such databases would constitute a geospatial information infrastructure reflective of the nation's transportation infrastructure. The Department of Transportation should join the efforts of the FGDC and other organizations to establish interoperability standards for geospatial transportation information. Such standards should be promulgated throughout federal, state, and local transportation entities.

3. **Remote sensing experts should look for ways to apply geospatial information methodologies developed for other uses to strengthen the nation's ability to protect its critical transportation infrastructure.** For example, both geospatial analysis of urban infrastructure and evacuation plans for natural disasters can assist in the developing methods to strengthen critical transportation infrastructure. These and other sources of knowledge should be mined for their potential contribution to protecting transportation infrastructure.

4. **The U.S. Department of Transportation, working in conjunction with other federal agencies, state and local transportation authorities, the universities, and the private sector, should develop new methods of remote sensing analysis in support of critical transportation infrastructure.** The workshop fully endorsed the utility of remote sensing technologies in the effort to improve transportation security. However, it also noted that much more should be done to support the necessary research. Future progress will require not only additional funding for research, but also a coordinated approach to reduce duplication and redundancies.

NEXT STEPS

Refining The Research Agenda

The application of technologies, properly assessed, is a critical step in the attempt to meet the terrorist threat (Motteur 2000). The research agenda of Table 2 represents only a first step in developing geospatial tools necessary for improving protection of the nation's critical transportation infrastructure. Future workshops devoted to this topic should focus on presenting and assessing specific examples of successful geospatial tools and refining the future research agenda. In particular, it should provide a roadmap that specifies which applications should be pursued for the near-, mid-, and long-term. The resulting roadmap should also outline the steps required to achieve each phase of technology development. As noted in recent testimony (Williamson 2002) the process of moving from basic research to applications of utility to an end user is complex. Reaching the end user to respond adequately to the terrorist threat will require a detailed assessment, not only of the technologies, but also of the technology transfer process.

Developing an Outreach and Training Agenda

Future technology development efforts should also focus on creating an agenda for outreach to transportation managers, centered on demonstrating the utility of remote sensing technologies for their particular transportation security needs. This will require a continuing dialogue similar to the National Research Council's Transportation Research Board Remote Sensing and Transportation outreach.

In order to bring technologies developed for transportation security into the transportation assessment and planning workflow, remote sensing technology development efforts should include also an intensive training effort focused on the work force that will need to employ the tools on the job.

Investigating Non-U.S. Experience With Terrorist Attacks

The workshop did not address directly the extensive experience with terrorist attacks on transportation lifelines in other countries, most notably on surface transportation facilities. Yet, these attacks often result in loss of life. "While roughly 20 percent of all incidents of international terrorism involve fatalities, the proportion of attacks on surface transportation systems involving fatalities is significantly higher. About two-thirds of the attacks on surface transportation have been intended to kill, and about 37 percent of the total involve fatalities" (Jenkins 2001).

Terrorism is an international problem, and other countries have had more experience with it than the United States. Hence, this nation can learn by examining the experience of other countries in combating terrorist acts focused on, or in association with, transportation facilities. Hence, a future workshop should include participants who have expertise in the methods used in other countries to combat and/or respond to terrorist acts. For example, a researcher in France has recently designed a GIS tool for the Paris region transportation authority (RATP) that provides real time dynamic mapping of security incidents that occur throughout the bus, train and subway network. The GIS tool has reportedly become highly effective in planning effective prevention of attacks (Miserey 2002).

A comprehensive examination of the use of remote sensing and related geospatial technologies should include a detailed study of the potential for these technologies to assist in detecting and interdicting possible similar attacks in the future.

ACKNOWLEDGEMENTS

This paper was drawn directly from the report, *Remote Sensing and Transportation Security*, published by the Safety, Hazards, and Disaster Assessment Consortium (NCRST-H) of the National Consortia on Remote Sensing in Transportation (NCRST), written by Ray A. Williamson, Stanley Morain, Amelia Budge, and George Hepner. The workshop and report preparation were supported in large part by the Research and Special Programs Administration of the Department of Transportation.

REFERENCES

Jenkins, B. M. (2001). Protecting Public Surface Transportation Against Terrorism and Serious Crime: An Executive Overview, *Minetta Transportation Institute Report 01-14*, October.

Miserey, Y. (2002). *Le Figaro*, April 15, p14.

Motteur, R. (April 2002). *Technology Assessment in the War On Terrorism and Homeland Security: The role of OTA*, Report prepared at the request of Hon. Ernest F. Hollings, Chairman, The Committee on Commerce, Science, and Transportation, United States Senate.

Williamson, R. (2002). Meeting State and Local Needs for Space-based Data and Information, Testimony before the Subcommittee on Space and Aeronautics of the Committee on Science, U.S. House of Representatives, Kansas City, KS, May 20.