U.S. DEPARTMENT OF TRANSPORTATION • National Consortia on Remote Sensing in Transportation

NATIONAL CORSORTIUM for SAFETY, HAZARDS AND DISASTER ASSESSMENT of TRANSPORTATION LIFELINES

Workshop Report

Remote Sensing for Transportation Security

Sponsored by the
Consortium for Safety, Hazards, and Disaster Assessment

National Consortia for Remote Sensing in Transportation

Remote Sensing for Transportation Security

Report of a workshop held at the Space Policy Institute,
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National Consortia for Remote Sensing in Transportation

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Executive Summary

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 Assessment 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 to meet the threat of terrorist activities directed at transportation facilities.

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. Remote sensing data and methods can help reduce the vulnerabilities of the U.S. transportation system and lessen the risk of attack.

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. Remote sensing from aircraft allows 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.

This initial 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 follow-on workshops focused on identifying research agendas for specific elements of the nation's transportation infrastructure.

Executive Summary

Findings

The workshop arrived at four groups of "findings," or conclusions that reinforce the need to more effectively coordinate efforts among emergency response agencies.

Finding 1: 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 2: 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 3: 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 4: 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

Sharing information to effectively plan and implement response teams is vital to the security of our nation.

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, geospatial analysis of urban infrastructure and evacuation plans for natural disasters can both assist in 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.

Introduction

The workshop arrived at four groups of "findings," or conclusions that reinforce the need to more effectively coordinate efforts among emergency response agencies.

The nation's transportation networks function as lifelines of commerce, security, and recreation. They are also vulnerable to attack and severe disruption. As officials have discovered since September 11, protecting and preserving the extensive U.S. transportation networks against terrorist attacks remains a daunting task. Fortunately, today's powerful geospatial tools (Box A), especially remote sensing, positioning, navigation, and timing (PNT), and geographic information systems (GIS), can assist in this crucial effort.

Following September 11, the National Consortia on Remote Sensing in Transportation (NCRST) were asked by DOT's Research and Special Programs Administration (RSPA) to incorporate critical infrastructure protection into their ongoing activities. For the safety, hazards, and disaster assessments consortium (NCRST-H), this is a logical extension of technology being developed and deployed for application by state, local, and municipal transportation authorities; nevertheless, the realities of today's geopolitical circumstances require new thought processes and strategies to cope with deliberate acts of aggression against civilian facilities. Terrorist acts may appear to the public as random and unpredictable, but to transportation planners they represent premeditated events that careful planning can possibly avoid or mitigate by developing transportation systems that promote resiliency and redundancy[1]. Many of the remote sensing products being developed and deployed by this consortium are ideal for responding to these challenges, and many more can be adapted quickly and inexpensively to improve the security aspects of transportation lifelines.

America's transportation infrastructure is a reflection of the nation's economic vitality, which in turn is predicated on maintaining stable economic, political, and social environments. Under most circumstances the nation's transportation system works smoothly

Box A. Geospatial Technologies

- *Geographic Information Systems (GIS)*
- *Position, Navigation, and Timing (PNT)*
    - *Global Positioning System (GPS-US)*
    - *GLONASS (Russia)*
    - *Galileo (future European system)*
- *Remote Sensing*
    - *Imaging*
    - *Non-imaging*

[1] As used in this report, *redundancy* refers to replicated systems or subsystems that can be invoked for fail-safe security in the event that a primary system is destroyed.

and efficiently; but, as President Eisenhower recognized in authorizing the Interstate Highway system during the Cold War 1950s, it is vulnerable to attack from unexpected quarters. Although the U.S. public had become accustomed to peaceful stability within U.S. borders, the appalling events of September 11, 2001 require a shift in thinking. While the transportation system cannot be re-engineered in its entirety to cope with this new operational environment, a variety of strategies can aid in protecting its many modalities and components. Among these is a higher use of aerial and satellite imagery (and collateral sensor data from non-imaging systems), to obtain intelligence for situations that develop rapidly and which demand real-time decision-making.[2]

The transportation system is extensive, complex, and critical to maintaining the U.S. economy. The White House report, *Securing the Homeland, Strengthening the Nation*[3], underscores the urgency of strengthening transportation security. The new Transportation Security Administration within the Department of Transportation is designed to provide a focus for federal efforts on transportation security.

Box B. The Enormity of the Task

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.

Table 1. Estimated Extent of America's Transportation System (Source: DOT/RSPA)

System	Infrastructure	Use
210 million vehicles	4 million miles of road 500,000 bridges (1/3 of 127,000) urban bridges serve as maor arterials	4 trillion passenger-miles 920 billion freight ton-miles
1.2 million railroad cars 250 intercity Amtrak trains	150,000 track miles	1.3 trillion ton-miles 20 million passenger 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 each year through major U.S. ports

[2] General Accounting Office, *National Preparedness: Integrating New and Existing Technology and Information Sharing Into an Effective Homeland Security Strategy*, GAO-02-811T (Washington, DC: General Accounting Office June 7, 2002: http://www.gao.gov/cgi-bin/getrpt?)
[3] See http://www.whitehouse.gov/homeland/) or http://whitehouse.gov/homeland_security_book.html.

Workshop Purpose, Goals, and Expected Outcomes

The NCRST-H consortium has responded to the appeal for developing new technologies and methods designed to tackle the threat of terrorism on U.S. soil by organizing a workshop to develop a national research agenda. This initial effort focused on refining and improving the role that remote sensing and other geospatial technologies have in enhancing the security of critical transportation infrastructure. The scope of the need for improved transportation security and the wide variety of transportation modes involved suggested that a single workshop would only begin to provide a blueprint for near- and mid-term action. Consequently, this workshop was specifically designed to explore the range of transportation security needs and to provide a basis for future, more narrowly focused, workshops on specific modes or technologies.

This workshop was designed to:

1) Characterize the needs for improving transportation security in all phases of the terrorism challenge (Box C);
2) Explore how imagery, sensor data, and geospatial technologies provide meaningful assistance toward improving security;
3) Characterize the current technological state-of-the-art for addressing categories of need (preparedness, prevention, mitigation, post-event recovery) across major types of transportation lifelines;
4) Identify critical future research and development areas;
5) Identify education and outreach needs;
6) Provide guidance for structuring additional workshops focused on specific transportation modes and technologies.

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

Remote sensing technologies include both imaging sensors and non-imaging sensors (Box A, page 6). 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.*

To initiate dialogue, several brief presentations were scheduled (see Appendix A for a list). The presentations served also to orient participants and to focus discussion. In planning the workshop, we expected to achieve:

1) A better understanding of how NCRST-H can fulfill its expanded mission;
2) An understanding of general roles for remote sensing at state and local levels;
3) An outline of future research, engineering, and applications development;
4) An interim consensus of which remote sensing technologies (sensors and methods) hold the greatest promise for enhancing transportation security;
5) A preliminary list of ways in which the remote sensing community can facilitate improvements in transportation security.

Potential of Image & Sensor Data for Improving Lifeline Security

Remote sensing technologies, together with GIS and PNT 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 workshop addressed a spectrum of infrastructural and technological issues, including:

• Which elements of the transportation infrastructure are considered most vulnerable for transportation security?

• How are these critical elements geographically distributed across the nation?

• What attributes of these elements are amenable to inventory, assessment, protection, interdiction, and/or mitigation efforts using aerial and satellite sensors?

• What are the optimum resolution requirements for spatial, spectral, radiometric, and temporal data collection for different transportation elements?

The workshop also began to match critical infrastructure protection needs with appropriate geospatial technologies by:

• Identifying current and emerging remote sensing technologies for deployment in critical infrastructure protection;

• Assessing which of these technologies have utility for regional, local, municipal incident management;

• Beginning to identify integration requirements for delivering quality information to users in appropriate time frames.

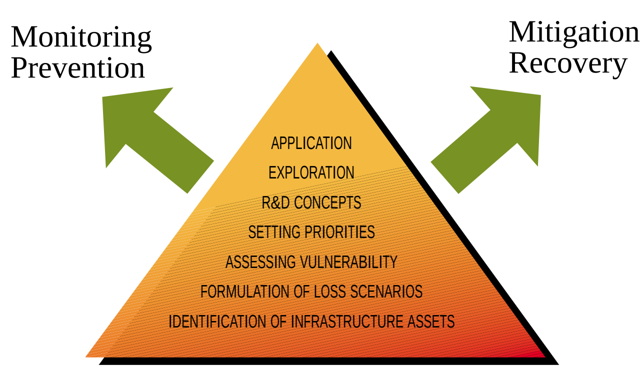

Figure 1. The flow of research to applications in support of transportation security.

Findings

The workshop arrived at four groups of "findings," or conclusions, the first three of which are related to the overall production and use of geospatial data. The fourth finding focuses on creating a broad research agenda.

Finding 1: Local, state, and federal responses to the events of September 11, 2001, illustrate a 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.

The September 11 attacks have forced a reevaluation, not only of the security aspects of U.S. critical transportation infrastructure, but also of the nation's institutional policies toward access to, and use of, information. Workshop participants noted, for example, that current policies governing collection, use, and sharing of critical geospatial information inhibit efficient use of these data in developing mitigation procedures and in responding to terrorist threats and actions. On the one hand, the potential for misuse of critical information has caused federal and state agencies to restrict access to information by removing it from the Internet and other public venues. On the other, combating the threat of terrorism and responding to future attacks will require more effective sharing and use of geospatial data and information. It will also necessitate within the geospatial community the continued improvement of analytical geospatial methods and software directed at improving transportation security.

Accordingly, the nation needs new institutional policies to support coordinated efforts in support of improved transportation security and coordinated emergency response. The need for interoperability of communications systems is widely understood;[4] the need for interoperability of geospatial information is less well understood. Workshop participants recognized that meaningful progress toward preparing the nation for both prevention and response to attacks on elements of the nation's transportation networks requires coordinated efforts by agencies across the federal government: among federal, state and local governments, as well as among government and private sector geospatial data providers and analysts. For example, it is little recognized by the general public that in addition to destroying two large buildings and killing nearly 3000 people, the attacks on the World Trade Center severely affected New York's transportation lifelines, making rapid response by emergency workers especially difficult. Throughout the cleanup process, transportation routings near the ruins of the World Trade Center changed daily and even hourly, making timely map updates necessary. Although the agencies and individuals who responded to the challenges of saving lives and cleaning up after the attacks accomplished wonders despite having no advanced warning and working in extremely dangerous conditions, the lack of established coordination plans slowed their efforts. In effect, the teams "made do" with what they could cobble together in terms of base data and imagery acquired by daily aircraft overflights, which commenced only on September 14, three full days after the attacks.[5]

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[4] See, for example, the statement of Bruce Baughman Office of National Preparedness, Federal Emergency Management Agency, before the Committee on Transportation and Infrastructure, Subcommittee on Economic Development, Public Buildings, and Emergency Management, U.S. House of Representatives, April 11, 2002.

[5] Jerry Dobson, "How Will GIS Help Fight the War on Terrorism?" *GEOWorld: http://www.geoplace.com, November2001.*

Fortunately, thanks to the many individuals and organizations willing to help, they were eventually able to provide coordinated mapping, GPS, and imagery information in a rapid fashion.[6] Nevertheless, this coordination was more a reflection of individuals committed to taking action in the face of a massive problem than the result of prior planning by the responsible local, state, or federal agencies. These organizations could have put teams in place and worked more quickly and effectively if the institutional policies of their various agencies had encouraged the sharing of information and responsibility for response.

There should be coordinated and regular exercises with state and local governments with the specific intent of testing database interoperability. It is also critical to understand first hand what the response community needs, wants, or expects. Developing databases based on what federal agencies believe will be needed and useful is important, but if the databases are intended for use by the responding entity (police or firefighters) then they need to be in formats that such groups can use effectively. In particular, local responders will likely not wish to work with new products in an emergency. Bringing new products (and iterations of them) online can be accomplished through a series of data-sharing exercises. For example, the atmospheric dispersion models that NOAA generates from programs such as CAMEO are models that the fire management community currently uses. They want those products because they are familiar with them. When improving such a product, agencies must be sure that the model will still run at the lowest level of capability and in a familiar output format.

The geospatial data and information developed for other uses can also support improvements in transportation security. One of the strengths of a geospatial information systems approach is that one comprehensive database for a region can support many different applications. For example, as several workshop participants noted, much of the information developed by state and local communities to support infrastructure planning can be used to mitigate the threat of terrorist attacks or to enhance the speed and effectiveness of emergency response teams in case of attack or natural disaster. However, to be fully useful in combating potential terrorist threats, the structure and content of geospatial databases, including remotely sensed imagery, will have to be reviewed for applicability in improving transportation security. In some cases, the existing framework and transportation databases will need to be enhanced.

The need to improve critical infrastructure protection has created new requirements for remote sensing and GIS analysis. Workshop participants argued that in order to reap the benefits of data and information from non-transportation sources, it will be necessary to develop analytical software designed especially for the security mission. Such software and methods need to be widely available to provide comparable analytical capabilities across the United States. New analytical methods in RS/GIS specifically devoted to supporting critical infrastructure protection could greatly strengthen the nation's ability to improve transportation security. Particular attention should be given to a significant, but limited, number of critical transportation assets (e.g., pipelines, bridges, ports, intermodal facilities), rather than attempting to develop functionalities that encompass everything.

Some remote sensing methods that have been developed for military applications may be transferable to civilian security use. However, civilian measures must consider economic, social, and legal aspects that are less relevant in a purely military situation. The measures must be designed for high reliability. Needs include:

• New methodologies and research to identify, assess, and monitor high-value, highly vulnerable transportation facilities across the United States;

• New methods of analysis and use of sensor and imagery assets to assess vulnerabilities, monitor assets, and aid in post-event recovery. For example, sensitive non-imaging sensors that can detect chemical, explosive, or radioactive plumes could help in monitoring container cargo ships from aircraft or bridges under which all ships in a port must pass.

[6] Bruce Cahan and Matt Ball, "GIS Ground Zero: Spatial Technology Bolsters World Trade Center Response and Recovery, " *GEOWorld: http://www.geoplace.com, January 2002.*

Finding 2: Remote sensing technologies would be a major asset in identifying and mitigating transportation security weaknesses throughout the United States.

In the past, security has not been a primary consideration in transportation planning. The U.S. transportation system as it now exists possesses many vulnerabilities that could have been avoided with careful advanced planning. For example, in some cases, critical infrastructure elements have by chance been co-located with high-value, vulnerable facilities, such as petroleum refineries or power plants. Such co-location has been a matter of convenience or of a previous lack of concern about terrorist attack. Remote sensing technologies can assist in identifying previously overlooked vulnerabilities. Over the longer term, the need for instituting extensive security measures can be reduced by using remote sensing analysis to reduce those vulnerabilities. The planning process should emphasize decentralization of facilities and redundancy of the functions of those facilities. In this way individual facilities, be they pipeline corridors or roadway conurbations, are reduced in their critical role in the network and their attractiveness as targets. Future planning and implementation of transportation lifeline facilities must have security as a primary consideration.

Finding 3: 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 in the attempt to enhance U.S. transportation security. Currently, in attempting to use transportation databases, users often experience limitations on availability, integration, and use of geospatial data and technologies for transportation security. Workshop participants pointed out that the information regarding the nation's information infrastructure is widely dispersed in a variety of databases, in a multiplicity of formats and software. Hence, many of these databases are not readily interoperable, making the task of using them especially difficult in times of crisis.

In particular, there is a lack of suitably interoperable technical standards, both for data sharing and for operating hardware and software. Although the Federal Geographic Data Committee (FGDC) has established federal standards for preparing and sharing geographic data, which have done much to improve interoperability among geospatial databases at the federal level, much more needs to be done on the state and local level to reap benefits in times of crisis. State and local databases often lack sufficient interoperability in emergency situations, whether caused by natural disasters, human error, or deliberately by terrorists. Yet, most emergency situations involving transportation systems, either actively or passively, will involve state and local agencies and jurisdictions. The FGDC has recommended several actions that, if accomplished, would sharply improve the nation's security (Box D, page 14).[7] If extended to transportation, these recommendations would undergird the security of the U.S. transportation lifelines.

The various proprietary formats used by commercial software also present barriers to interoperability. Although proprietary formats are often important to the companies in differentiating products in the competitive marketplace, they can also serve as impediments to sharing information. Vendors should be encouraged, both through federal and state policies, to establish a greater level of interoperability than they now achieve, either through developing common formats or transferable formats. In some cases, it may be advantageous to develop software modules that

[7] See, for example, "Homeland Security and Geographic Information Systems," http://www.fgdc.gov/publications/homeland.html.

allow a high level of interoperability in times of crisis, but which are available only to authorized authorities and agencies.

Lack of uniformity of functionality (institutional interoperability) also impedes data sharing. In developing geospatial data sets, institutions understandably develop a set of data standards and formats to suit their data needs and their institutional modes of operation. However, databases developed in isolation from other institutions are generally only interoperable by accident. In order to meet the new mandate prescribed by the nation's response to the threat of terrorism, institutions will need to make greater efforts to develop geospatial infrastructures that are more interoperable.

Different data users have widely different skill levels, which can impede interoperability, especially during times of crisis. This impediment can be tackled by increasing the educational opportunities for geospatial professionals working in transportation fields. In particular, although many transportation geospatial professionals have developed considerable skill with GIS methods, as a whole they do not yet have much experience with remote sensing and the significant extra capability that remotely sensed data can impart to their efforts.

Policy restrictions on access to critical data and information increase response time and reduce efficiency. Most of the above impediments can be solved by giving greater attention to developing standards for data interchange and software interoperability. These are technical issues that have technical solutions. Although achieving the desired level of database and software interoperability often requires additional funding and time, a number of committees are working on the issues. The policy restrictions on access that are put in place by local, state, and federal authorities cause potentially more serious impediments in using the nation's geospatial information infrastructure to improve transportation security. Often, for example, the "owners" of geospatial data are simply not willing to share them with other institutional entities, despite the demonstrated need. Here again, the experience with data sharing in responding to the World Trade Center emergency and clean-up efforts suggests that much more needs to be done to improve the process.

BOX D. Recommendations of the FGDC

1. *Address gaps in the nation's geospatial database infrastructure by supporting:*
   a. *National data standards*
   b. *Completion of all National Spatial Database Infrastructure Framework Themes*
   c. *Nationwide geospatial data compatibility for E911 operations*
   d. *Compilation of comprehensive georeferenced information on Critical Infrastructures*
2. *Bring additional focus on these activities to elected officials at all levels of government across the Nation.*
3. *Promote, enhance, and provide sufficient resources for collaborative relationships between federal, state, and local agencies, and with the private sector.*
4. *Develop uniform approaches to planning for Homeland Security events while relying on standardized data and systems.*
5. *Develop sophisticated mobile GIS labs and trained staff that can be delivered to any site in the Nation within 12 hours of an event.*

Source: http://www.fgdc.gov/publications/homeland.html

Finally, creating a geospatial infrastructure could build on the existing Intelligent Transportation System (ITS) infrastructure and information investments, with which the geospatial infrastructure is complementary. Hence it will be important to find and exploit potential synergies between the two efforts.

Finding 4: Research, development, testing, and evaluation should focus on creating products specifically designed to fit transportation security needs for all aspects of the terrorist challenge.

Workshop participants voiced two schools of thought regarding the efficacy of using spectral imaging for protecting transportation lifelines (Box C, page 9). One group argued against focusing on detection, interdiction, and prevention of terrorist attacks, largely on grounds that the costs of protection against such statistically small odds are great and cannot be sustained in an economy constantly adjusting to new circumstances. The second made a case that centering primarily on using geospatial technologies for responding to attacks begs the true value of image-derived intelligence. Detection, interdiction and prevention requires additional technology development, but the pay-offs would provide significantly more security to support the needs of public safety and incident management. Moreover, promising technologies such as imaging scanners and non-imaging devices sensitive to specific environmental phenomena are already in the proof-of-concept stage. The use of aerial photography for hazard and disaster assessments is already standard practice, and use of more sophisticated electro-optical sensors has gained ready acceptance in defense arenas and among first responders to domestic terrorist acts. Although workshop participants differed concerning which technological areas they would emphasize for research and development, they nevertheless agreed that all elements of the terrorist threat need to be met and that, where feasible under considerations of cost and efficiency, remote sensing and other geospatial tools should be developed to the fullest extent of their potential.

Workshop participants agreed that first responders and transportation planners need to be more aware of the capabilities of products derived from remotely sensed imagery to supply critical information necessary for managing emergencies, whether they are responding to terrorist actions, human accidents, or natural causes. They also agreed that sensor data, whether from imaging or non-imagimg sensors, should be integrated with existing geospatial databases. If this is done in the spirit of *preparedness*, the costs and benefits can be allocated across both Homeland Security and traditional transportation planning accounts.

The Value of Remote Sensing for Critical Infrastructure Protection

Workshop participants engaged in general discussions about remote sensing techniques following each of the presentations (see Appendix A: Workshop Agenda). Several recurring themes emerged from these discussions, mostly related to information derivable from imagery, and in a lesser degree to knowledge obtainable from non-imaging sensor data (Table 2).

Table 1: Characteristics of information obtainable from imaging and non-imaging sensors

Image Data Products Allow Analysts To:	*Non-Image Sensor Data Products Can:*
View landscapes at different scales (scalability)	*Reveal precise object locations*
Recognize relationships between infrastructure elements, including vulnerabilities	*Detect trace amounts of biological and chemical agents*
Verify & update existing geospatial databases	
Visualize and integrate on-screen displays	
Detect aberrant activities through data mining	
Detect subtle changes in the landscape	
Monitor consequences of incidents	

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 Updating. 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 (Figure 2) 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 persepctive 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,

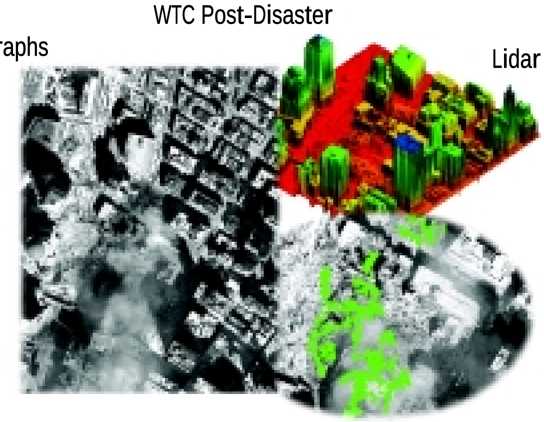

Figure 2. For a given area all densely populated buildings can be inventoried by time of day or other criteria, and the results included in attack scenarios. Lifeline and urban sensor data are also required for validation and updating. Incident management requires real-time input not available in databases. Imagery courtesy of EarthData and Urban Data Solutions.

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. Figure 3 displays an image of these spots, collected by EarthData International. These hot spots are detectable in the 3-5µ spectrum because they are much hotter than their surroundings. For detecting specific phenomena in the ambient landscape, a sensor operating in the 8-14µ 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.

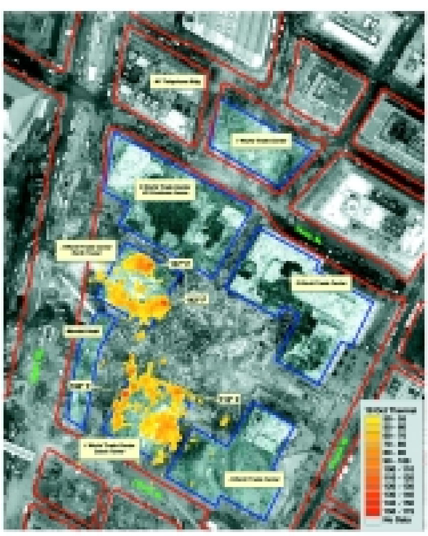

Figure 3. Thermal image collected on a flight over the World Trade Center on October 18, 2001, with the FLIR Thermacam SC2000. Areas that register above 50 degrees Farenheit (orange) are overlaid onto orthophotos generated from digital photography that was collected on October 7, 2001, with a Kodak Megaplus 16.8i camera. The building footprints and curb information from the New York City Landbase are depicted in blue and red, respectively. Image courtesy of EarthData.

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. Figure 4 shows an area near Las Vegas, Nevada where seasonal subsidence occurs.

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, as for that shown in Figure 5, 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, 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 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 unpiloted 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.

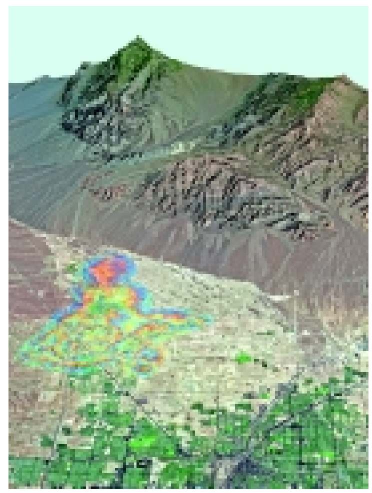

Figure 4. The rainbow pattern indicates subsidence near Las Vegas, NV resulting from ground water withdrawal. Such information is obtained from dual pass synthetic aperture radar phase data superimposed on high-resolution satellite radar and visible spectrum imagery. Courtesy NPA Group, Endenbridge, UK.

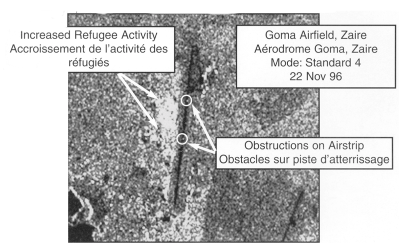

Figure 5. Goma, Zaire airport. Densely populated refugee camps are detectable, as are obstructions on the airport runways that prevent relief measures. Image courtesy of RADARSAT, International.

Recommendations and Next Steps

The bombing of the Alfred P. Murrah Federal Building in Oklahoma City, the attack on the USS Cole in Yemen, the destruction of the World Trade Center, and the insertion of anthrax into the U.S. postal system are all reminders that the United States has entered a new reality in citizens' assumptions regarding safety and security. These incidents scream for new ways to protect our transportation lifelines, to maintain the flow of goods and services, and to plan for large-scale public safety and evacuation. As a recent National Research Council report notes,'"The United States should take advantage of its scientific and engineering strengths to detect, thwart, and respond to terrorist attacks more effectively."[8]

One of the ways to accomplish these aims immediately is to make more effective and timely use of aerial and satellite surveillance and monitoring technologies by answering such questions as: How do we adapt the existing capabilities of image-derived information in the short-term to fit new operating circumstances, and what new ways of doing business will we need in the long-term to develop an infrastructure that is resilient to various forms of attack?

The strength of any paradigm shift is realized if new questions can be answered along with traditional ones. Using remote sensing technologies will address many, if not most traditional safety, hazard, and disaster issues facing transportation lifelines, as well as provide for those raised by deliberate acts of aggression. The White House call to action, *Securing The Homeland, Strengthening The Nation (see page 7),* supports this view implicitly. It carries frequent acknowledgments recognizing the need for interoperable information sharing among agencies at all levels of government as well as for modernizing the nation's emergency management system.

This report envisions linking:

1. The USGS National Map Initiative;

2. Government and commercial satellite imaging systems and environmental sensors comprising a global "sensor web;"

3. Development of "smart satellites" that self-position, orient, and point; and that have sensors with automatic, onboard data processing capabilities;

4. Ground-based incident management centers accessing next generation Internet and Web Mapping Services.

The aim of the new approach is to capitalize on these systems so that the nation is well prepared to deal with all aspects of the security threat (Box C, page 9). Then, if an incident occurs, appropriate authorities can invoke a regional incident management area that displays in 2-D, 3-D, and animations:

- The entire transportation infrastructure;
- The location of critical lifeline nodes throughout the incident area;
- The spatial relationships of these nodes to other critical elements in the physical, social, and economic sectors (e.g., schools, hospitals, banks, emergency response units, reservoirs, and power plants);
- Dynamic scenarios for interdiction, mitigation, response, and recovery.

Preparation for security threats will also assist preparations for mitigation and response to natural disasters, and vice-versa.

[8] National Research Council, *Making The Nation Safer: the Role of Science and Technology in Countering Terrorism* (Washington, DC: National Academy Press 2002).

This report has discussed a variety of ways in which the nation's transportation information infrastructure can be improved. Such improvements depend on the assistance and involvement of transportation and remote sensing professionals throughout the United States working at all levels in government and private institutions. The following recommendations follow from the workshop findings and from additional discussion and inputs beyond the workshop framework.

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. In many cases, current policies at all levels 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. Sharing critical geospatial information among these databases and among involved institutions will not be effective unless the databases that contain the information are interoperable. Hence, 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. As noted above, a geospatial transportation information infrastructure would share many characteristics with the intelligent transportation system infrastructure. Hence, researchers should explore ways to capitalize on potential synergies between the two.

3 *Remote sensing experts should look for ways to apply geospatial information and methodologies developed for other uses to strengthen the nation's ability to protect its critical transportation infrastructure.*

For example, geospatial analysis of urban infrastructure and evacuation plans for natural disasters can both assist in 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 the federal government will have to do more to support necessary research. Future progress will require not only additional research funding, but also a coordinated approach to reduce duplication and pursue collaborative, mission-oriented research.

Most workshop participants felt that a second or third workshop would be advisable in order to refine a research agenda. Table 3 represents a beginning in the process of developing a detailed research agenda, ranked in order of priority of importance to critical transportation infrastructure protection.

Table 3. Research agenda for using imagery and non-imagery sensor data to enhance transportation critical infrastructure security and safety

Lifeline System	(A) Near-Term (1-5yrs)	(B) Mid-Term (5-10yrs)	(C) Long-Term (>10yrs)
Roads (federal, state, county, municipal)	1. Interpret images to catalogue roadside conditions, identify critical nodes, and categorize road segments at risk; 2. Use input from A1 to help develop National Map database; 3. Create image archives and DEMs using existing sources and commercial data providers; 4. Begin 3-D modeling using A3 for incident management, and characterize highly vulnerable lifelines and infrastructures; 5. Intensify sensor R&D for bio/chemical agents; 6. Begin raster/vector integration to ingest image intelligence into existing GIS architectures; 7. Develop interoperable systems and infrastructures for data sharing, manipulation, and interpretation; 8. Begin to acquire and ingest advanced sensor data into routine, image-based applications (e.g. subsidence) developed by NCRST and others; 9. Establish high priority incident management areas (e.g. border crossings, urban areas; intermodal transfer points).	1. Identify subsidence patterns to reassess ramp speeds and other traffic hazards; 2. Expand 3-D modeling to less vulnerable lifelines; 3. Deploy bio/chemical sensors for tracking and interdiction; 4. Build and test incident scenarios; 5. Collect new sensor data for image fusions (e.g. subsidence, etc.) (Ref. A8); 6. Extend incident management areas to broader coverage (e.g. A9).	1. Update and refine image archives, features, scenarios, models; 2. Extend incident management areas to complete national coverage.
Bridges (inc. urban)	1. Use imagery to inventory, categorize, and prioritize bridges; 2. Use visualization and 3-D modeling to identify potential vulnerabilities for high priority bridges; 3. Create plans for fine resolution DEM data collection and production; 4. Develop data mining algorithms that detect changes.	1. Expand visualization and 3-D modeling for lower priority bridges; 2. Integrate image intelligence of roadside conditions with lower priority bridges for incident management; 3. Employ data mining on data archives for bridges (Ref. A4).	1. Extend 3-D modeling of bridges to complete national coverage (Ref. B1).

Table 3. Research agenda for using imagery and non-imagery sensor data to enhance transportation critical infrastructure security and safety

Lifeline System	(A) Near-Term (1-5yrs)	(B) Mid-Term (5-10yrs)	(C) Long-Term (>10yrs)
Railroad lines	1. Create image archives for high priority railway switching yards for time-series analysis of changing surroundings; 2. Interpret imagery for incident management and identify points of highest vulnerability; 3. Create plans for, and begin acquiring, sensor data for track subsidence measurements, and integrate with railroad ITS; 4. Integrate image intelligence of switching yards with other infrastructure elements; 5. Develop image intelligence around railroad tunnels and bridges.	1. Create national database of track segments subject to subsidence (Ref. A3).	TBD
Airports	1. Develop techniques for mapping airport obstruction surfaces; 2. Apply obstruction surface technology to high priority airports; 3. Develop image intelligence from 3-D visualizations to identify viewsheds usable for ground attack.	1. Extend obstruction surface technology to other priority airports.	1. Extend obstruction surface technology to complete coverage.
Watercraft	1. Interpret time-series images of major port facilities to develop intelligence about form and function, vulnerabilities, and relationships to intermodal links; 2. Identify jetties, breakwaters, and other harbor structures; 3. Develop methods to monitor ships prior to entering ports for potential weapons of mass destruction.	TBD	TBD

Table 3. Research agenda for using imagery and non-imagery sensor data to enhance transportation critical infrastructure security and safety (con't)

Lifeline System	*(A) Near-Term (1-5yrs)*	*(B) Mid-Term (5-10yrs)*	*(C) Long-Term (>10yrs)*
Pipelines and nodes	*1. Use pipeline database to prioritize vunerabilities; 2. Fuse pipeline vectors with imagery and DEMs to facilitate 3-D visualizations. 3. Integrate pipeline locations with road and rail networks in major urban complexes to identify critical nodes; 4. Interpret time-series imagery for right-of-way surface features to prepare anti-terriost plans and todentify changes requiring re-routing; 5. Intensify sensor R&D for detecting leaks and integrate these sensor data into interoperable GIS structures.*	*1. Expand integration effort to all urban areas and cities with >35,000 population (Ref. A3); 2. Commercialize and deploy new sensor systems for pipeline security and safetyt (Ref. A5).*	*1. Expand integration effort to complete national coverage.*
Ship and rail containers	*1. Develop UAV technology and light-weight bio/chemical sensors to identify contents of suspicious containers; 2. Transfer platform/sensor technology to Federal Railroad Administration, Transportation Security Administration, Coast Guard, Maritime Administration, Federal Motor Carrier Safety Administration, and cognizant state/local agencies to implement; 3. Invest in new sensor technologies for non-invasive interrogation of containers.*	*1. Expand container detection and surveillance technology to all national multimodal transfer points.*	*1. Globalize shipping container sensing program.*

Next Steps

Refining The Research Agenda. The application of technologies, properly assessed, is a critical step in the attempt to meet the terrorist threat.[9] The research agenda in Table 3 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,[10] 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.[11]

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.[12]"

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 useable in planning effective prevention of attacks.[13]

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.

[9] Ellis R. Motteur, *"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, April 2002.
[10] Ray A. Williamson, "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, 2002.
[11] TRB website: http://www.nas.edu/trb/.
[12] Brian Michael Jenkins, Protecting Public Surface Transportation Against Terrorism and Serious Crime: An Executive Overview, MTI Report 01-14, October 2001.
[13] Yves, Miserey *Le Figaro*, April 15, 2002, p14.

Appendix A

WORKSHOP AGENDA
March 13-14, 2002
Remote Sensing and the Security of Transportation Lifelines
Elliott School of International Affairs
2013 G St., NW, Room 103
The George Washington University

March 13

9:00	Welcome, Introductions, Review of Workshop Agenda *Dr. Stanley Morain*, Director, Earth Data Analysis Center, University of New Mexico
9:30	Challenges in Transportation Security: Research Issues and Priorities for Transportation Lifelines *Dr. K. Thirumalai*, DOT Research and Special Programs Administration
10:00	Transportation Lifelines and Homeland Security *Dr. Gerry Kauvar*, RAND
11:00	Remote Sensing and Transportation Lifelines *Dr. William Roper*, Department of Civil and Environmental Engineering, The George Washington University
11:45	GIS, the Internet, and Critical Infrastructure Security *Mr. Tim Abdella*, ESRI
12:15	Discussion
12:30	Lunch
1:30	Round Table Review of Critical Issues and Discussion *Dr. Ray A. Williamson*, Space Policy Institute, Chair (Selected participants invited to share 2-3 most critical issues (≤5 min each))
3:30	NASA's Potential Contribution to Aviation Security *Mr. Ron Birk*, NASA
4:00	Experiences with RS Data in the World Trade Center *Dr. Bruce Davis*, NASA Stennis Space Center
4:30	Discussion
5:30	Adjourn

March 14

8:30	Key Points from Day 1
8:45	Current DOT Security Needs: When and How Can Remote Sensing Help? *Dr. Aviva Brecher,* DOT/RSPA Volpe National Transportation Systems Center
9:30	Data Needs for Transportation Security: The Case of the World Trade Center, *Mr. Bryan Logan*, EarthData International
10:15	Discussion
12:00	Wrap-up and Adjourn

Appendix B

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Glossary

Digital Terrain Models (DTM/DEM): A digital terrain model or digital elevation model is simply a digital representation of a topographic surface. The data are stored in raster format with resolutions, e.g. distance between adjacent grid points, varying typically between 30-meters (satellite or aerial photography) and 1meter or less (LiDAR).**GPS** (Global Positioning System): A system of 24 earth oribiting satellites that are used to collect ground referenced data in x, y, and z coordinates using an installed or hand held device that is capable of receiving radio signals from at least four GPS satellites.

FGDC: The Federal Geographic Data Committee (FGDC) is an interagency committee, organized in 1990 under OMB Circular A-16 that promotes the coordinated use, sharing, and dissemination of geospatial data and information on a national basis.

Fuzzy Logic: A type of logic that recognizes more than simple true and false values but rather *degrees* of truthfulness and falsehood. In this way an attempt is made to apply a more human-like way of thinking in the programming of computers.

Geospatial Information: Information that can be linked to a specific geographic locality.

GIS (Geographic Information Systems): A computer-based data processing tool or methodology used for gathering, manipulating, and analyzing geographic information to produce a holistic, interactive geospatial analysis.

GPS (Global Positioning System): A system of 24 earth oribiting satellites that are used to collect ground referenced data in x, y, and z coordinates using an installed or hand held device that is capable of receiving radio signals from at least four GPS satellites.

Inertial Measurement Unit (IMU): IMUs consist of an all-attitude, four-gimbal, inertially stabilized platform and provide inertial attitude and velocity data to the GN&C (Guidance Navigation and Control) software functions, which in turn use the attitude data, along with state vector from the navigation software, to develop steering commands for flight control.

Light Detection and Ranging System (LiDAR): An instrument or sensor used commonly in remote sensing applications, that transmits light from an airborne sensor to the ground. Information regarding the speed and intensity of the reflected beam is then used to create a 3-dimensional model of Earth's surface in very high spatial resolution.

Position Navigation & Timing (PNT) Systems: Systems such as the Global Positioning System (GPS) that are capable of collecting data on the positioning, navigation and timing of any particular event. Others include the Russian GLONASS system and the future European Galileo system.

Radio Detection and Ranging (RADAR): Radar systems, as well as passive sensors operating at microwave wavelengths (slightly shorter than radar), are effective in detecting soil moisture and the surface texture of various physical features on the earth (e.g. calm seas vs. rough, turbulent water). Radar's advantage over other remote sensing systems is that it can function both in day and night as well as in cloudy conditions.

Raster: A spatial data model in which features are represented by picture elements (pixels), each pixel being assigned a particular brightness value and position that corresponds to a feature.

Remote Sensing: Information acquired by a sensor from a distance, without physical contact with the subject. Sensors may be mounted on a wide variety of platforms, including satellites, aircraft, or stationary objects. The human eye, coupled with the brain, is one of the most capable remote sensors known.

Synthetic Aperture Radar (SAR): SAR uses an antenna mounted onto a moving platform system (aircraft, satellite) to release microwave pulse signals and then measure their returns, integrating these to create a composite image that simulates a real aperture. Antenna lengths of up to 100 meters can be simulated using this technique.

Unpiloted Air Vehicles (UAVs): UAVs are aircraft capable of operating without an internal pilot; are tethered by a radio control link; and can be preprogrammed for both flight and payload operations prior to launch. UAVs have been employed by the DoD to perform a multitude of inherently hazardous missions that present unacceptable risks for piloted aircraft. They were most recently used in the war against the Taliban in Afghanistan.

Vector: A vector file is a file where lines and arcs are stored as vector coordinates—that is, as precisely defined entities with beginnings and ends rather than as lumpy groups of pixels.

Viewshed: A viewshed is the area on the ground that is visible from a specified location or locations. Creation of a viewshed from imagery typically uses DEM data to analyze the slopes of different cells between the source point and the entire DEM or one specific destination point using line-of-sight (LOS), which is a horizontal line connecting two points.