Spatial Data Fusion for Infrastructure Condition Assessment

by

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ABSTRACT

Information systems and their application to infrastructure management and protection with particular focus on transportation infrastructure are addressed in this paper. The opportunities for information systems leveraging geospatial and other data sources are presented. Remote sensing imaging and non-imaging sources of information are explored. Coordination and sharing of in information is explored to improve the ability of multiple organizations to more effectively manage and respond to disasters and infrastructure condition assessment issues. These include 3-D visualization, thermal infrared imagery, LIDAR data systems, IKONOS one-meter panchromatic imagery, SPOT imagery and the use of digital aerial imagery. The general area of disaster response management is also addressed and the findings of various studies in this area are summarized. Recommendations for the use of information systems and geospatial sensors and products in the future for transportation infrastructure condition assessment and protection are presented.

Keywords: Information systems, Transportation infrastructure protection, Infrastructure condition assessment, Geospatial information, IKONOS satellite data, Digital imagery, Data management, Disaster management, LIDAR, Infrared remote sensing, GIS mapping, Global Positioning System

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1.0 INTRODUCTION

Infrastructure managers at all levels face unprecedented challenges today. Increasing demands are being placed on agencies to preserve the existing infrastructure system and to take on new missions of improved

system safety and security management. A variety of advanced technologies are available to enhance planning, designing, managing, operating, and maintaining all aspects of the nations public and private facilities. The national transportation system is one example of a major part of our infrastructure system and a critical asset for national growth and development. Aerial and satellite remote sensing represents one area of rapid development that can be leveraged to address these challenges. These technologies have significant and unique potential for application to a number of cross cutting transportation security and infrastructure condition assessment issues.

2.0 INFORMATION SYTEMS CONSIDERATIONS FOR INFRASTRUCTURE CONDITION ASSESSMENT

It is clear that despite excellent efforts by many groups the approach to providing information for disaster management is not often effectively utilizing a wealth of data that resides, with various organizations. This existing information and technology could provide disaster mangers important information products that could save lives, reduce damage to property, and lessen the environmental impacts of disasters. The current situation is characterized by numerous shortcomings that inhibit optimal decision making for disaster management. The inability to access information and the lack of standardization, coordination, and communication are all obstacles that need to be overcome.

2.1 Information Management Goals

Considerable effort has been expended throughout the Disaster Management community to articulate issues and to characterize the dynamics and the inter-relationships that needs to be accommodated in a viable information management strategy. An important guide for this effort is found in the recommendations made by the Board On Natural Disasters (BOND) in their report to the National Research Council. The BOND's primary goals as articulated in its charter were to:

1. Improve decision making for emergencies through better access to quality data and information
2. Identify users and their needs
3. Provide information products specifically designed to meet users' need
4. Promote efficiency and cost effectiveness
5. Stimulate and facilitate mitigation

These are important components in any workable framework for comprehensive disaster management. However, the focus here is directed towards derived products, procedure and protocol. It is important that the process develops baseline products and implement solutions that reflect the complex fabric of the disaster management community. This work is done at a lower, more formative level in the information management life cycle and in fact forms the basis for the production of the products referred to by the BOND. As noted above the assessment process will work to identify the constituent components associated with specific disaster events and scenarios. The constituent components will then become the basis for technology specifications and the delivery of capabilities that encompass the products identified by the BOND.[1]

2.2 Data Management Considerations

This section provides assumptions based on information and conclusions that have emerged from recent studies in disaster management community itself. These assumptions certainly do not constitute and exhaustive set of parameters. Rather, they provide a point of departure and a set of "operating hypotheses" that can be used to help frame discussion and consideration of needs and requirements. Available Information and capacity is not uniform, consistent and standardized for disaster managers. Large cities may have invested millions of dollars in their information systems, while smaller municipalities may be operating with one personal computer. Disasters will constantly crosscut established boundaries. A fundamental problem in dealing with disasters is that they do not respect boundaries that include organizational, political, geographic, professional, topical, or sociological consideration.[2]

Disasters will often overwhelm mechanisms for coordination and communication. In addition, the mechanisms to bring data and information to decision makers are uncoordinated. Information is often produced from disparate sources and transmitted in whatever format the provider prefers, requiring significant effort to compile it into a form that provides a coherent picture or even thwarting integration altogether. Data standards are often inconsistent, and, even more dangerous; users are sometimes unaware of the limitations and uncertainties in data or are presented with conflicting interpretations of data without the means to assess the reliability of the sources. All of these issues reduce the efficacy of the decision-making process. The problem is compounded because information delivery systems in many cases become overloaded during crises. For instance, in 1996 a moderate (magnitude 4.7) earthquake in San Jose, California, led to more than a million attempted hits in less than one day on the U.S. Geological Survey's World Wide Web earthquake information server.[3] Most of those attempts were unsuccessful, including those by emergency managers trying to access data and information to aid in the formulation of a response plan.

3.0 INFORMATION MANAGEMENT PROCESS ISSUES

Disaster management is an exercise in logistics and information processing and distribution. To effectively undertake these tasks requires a good understanding of disaster information requirements and the characteristics associated with disaster events knowing that each event is uniquely different. Disasters come in different sizes, have different behavior and can be categorized on the basis of their impact on natural resources, agriculture, communities etc. They can also be discriminated and classified along a number of dimensions including impact, severity, duration, geographic setting and advance warning (NAPA 1998). In order to develop the Information Technology architecture for case scenarios application it is essential to understand the disaster event from the perspective of those responsible for assimilating the data. The effective use of this information for producing operational plans to deal with the disaster event and its aftermath is critical.

3.1 Consideration of Infrastructure Information Phase Management

For instance, it is important to appreciate that the four basic phases of disaster management may actually manifest themselves in different ways depending on the nature of the disaster. The mitigation phase is essentially a continuous process of preparation, analysis of performance and subsequent modification and refinement. As a result it will likely exhibit the smallest amount of variance. However, the other phases (preparedness, response and recovery) will likely have significantly different attributes depending on the nature of the event. For example consider the difference in the preparedness phase that would be associated with major seasonal flooding along the Mississippi or the Missouri Rivers, the Chaparral fires along the Pacific Coast, a Tsunami that impacts much of the Pacific Rim and an earthquake such as Northridge or Loma Prieta. In each case the geographic coverage and the amount of time for planning and staging is very different. As a result, many of the other systemic aspects of the disaster management initiative will be different as well.

An event warning which impacts the manner in which the preparedness phase is managed also has implications and consequences for the recovery phase (e.g. In the case of the Loma Prieta earthquake the emergency response resources were directed to the bay area despite the fact that Santa Cruz and Watsonville had more significant damage). Partially as a result of this California is building the Tri-Net seismic sensing network to measure shake and model damage in order to make more informed decisions regarding staging recovery resources.

3.2 Infrastructure Disaster Management Communities

The disaster management is extremely heterogeneous. In order to develop effective systemic solutions to the needs of this community any framework must address the need to effectively and efficiently share information across institutional boundaries within and between the groups that make up this community. In essence an interface must be specified at each boundary that separates levels in an agency or at the juncture between different agencies or between different sectors. These interfaces each have at least three components: 1) technical, 2) institutional and 3) institutional administrative. The importance of these interfaces is also proportional to the difficulty of implementing them in an automated context. For instance, the lightest weight interfaces should be between levels within the same entity within a single sector. In contrast the heaviest interfaces would be those that attempt to span sectors.[4]

A number of these communities have made significant institutional investments in the construction of foundation data products that feed modeling, analysis and decision support in a range of contexts. Not surprisingly the situation in the disaster management community in regard to data parallels spatial data issues across the federal government and throughout state and local government and the private sector. The BOND also addressed the issue of data sharing by the disaster management community. Their findings recognized that despite the importance of significant databases, their utility is impaired by a host of problems deriving from incompatible formats, inconsistent geographic reference systems, conflicting standards, and other human-caused factors. Many of these problems could be resolved and the value and utility of the databases for disaster decision making greatly enhanced through improved organizational and technological coordination with only an incremental increase in cost.[5] This is clearly in the public interest to accomplish this.

Disaster management scales for international agencies and governments to the individual. However, a very significant level of responsibility is vested at the local level. For instance, it is the on the ground officials, many of whom are local, that ultimately play the role of first responders (e.g. police, fire, medical and public works) and who also manage many of the recovery operations. To be effective in this context protocols must define communications, database structure, data formatting, hardware and software requirements, networking, quality control, and other issues needed to assure the linkage will improve decision making before, during, and after emergencies through improved access to quality information. In addition, such a linkage will provide information products that are specifically designed to meet the needs of users

3.3 Common Characteristics of Disasters

Disaster management is not a linear process that can be documented easily in a flow chart with a readily apparent beginning and absolute end point. Rather, it is a cyclical process of approximation, response and re-calibration that involves many different actors whose roles in relation to one another are likely to change based on circumstances and the stage in the process. The one constant evident in the process is the chaos that drives the system. Another absolute is that the effective, efficient application of information technologies and products has the capacity to improve the system in a number of ways that will combine to save lives, mitigate overall damage, conserve resources and ameliorate human suffering.

To develop effective architectures and technologies that meet the needs of the disaster management community there must be a precise understanding of the disaster management life-cycle (Mitigation, Preparedness, Response and Recovery), the Information Communities that combine to define the disaster management community and the information processing requirements associated with the cycle of data development, dissemination, analysis and review. In addition, and perhaps more importantly, there must be a precise understanding of the dynamics between these components and the “interfaces” that these dynamics imply. Only with such an understanding can we effectively model the process and derive technology solutions that map well into the business model of disaster management.[6]

3.4 Data and Information Processing Requirements

Data needs, the characteristics of data and the ability of data to contribute to analysis, response and recovery is well understood. The basic attributes of information that are considered most important by this community include:

1. Timeliness: delivery of data and information in time to drive decision-making

2. Consistency: delivery of data and information in a consistent, uniform manner
3. Understandability: delivery of data and information in a manner that is appropriate and understandable to the target community
4. Accuracy: precision in measurement and observation
5. Flexibility: adaptability to multiple situations

These information attributes have evolved over time within the disaster management community representing the viewpoint of a range of providers, users and consumers scaled from the local to national level. In this regard the communities involved transcend boundaries between recognized sectors at each of these levels (private, public, not-for-profit, NGO etc.).

4.0 TRANSPORTATION INFRASTRUCTURE INFORMATION SYSTEMS

The nation's transportation networks function as the 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, especially remote sensing, positioning, navigation, and timing (PNT), and geographic information systems (GIS), can assist in this crucial effort.

4.1 Overview of America's Transportation Infrastructure

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 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 coping 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.

The transportation system is extensive, complex and critical to maintaining the U.S. economy (see table 1). The Administration's report, *Securing the Homeland, Strengthening the Nation*[7], underscores the urgency in strengthening. transportation security. The proposed 2003 White House budget includes not only the establishment of a Transportation Security Administration within the Department of Transportation, but requests $4.8 billion "…to fulfill the mandates established by the [Aviation and Transportation Security Act of 2001]."

4.2 Potential of Image & Sensor Data for Improving Lifeline Security

Remote sensing technologies, together with other geospatial technologies such as GIS and PNT systems, have a significant role to play in the improvement of the Nation's transportation security and critical infrastructure condition assessment. 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 provides the ability 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 and drawbacks for use in transportation, and in particular, for the security of the Nation's complex transportation networks.[8]

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

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

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. For example, current policies governing the collection, use, and sharing of critical geospatial information inhibit the most 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 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;[9] the need for interoperability of geospatial information is less well understood. Workshop participants recognized that meaningful progress toward preparing the nation to prevent and respond to attacks on elements of the nation's transportation networks required the coordinated 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. 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 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 over flights, which commenced on September 14, three full days after the attacks.[10] 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.[11] This coordination was more a reflection of individuals committed to dealing with 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 institutional policies of their various agencies had encouraged the sharing of information and responsibility for response.

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 their 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. 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 the support of 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, inter-modal 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 be less relevant in a purely military situation. The measures must be designed for high reliability. Needs include:

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

2. 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.

Remote sensing technologies could 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 in time assist in reducing some of these vulnerabilities. Over the longer term, the need for instituting extensive security measures can be reduced by preemptive planning of lifeline facilities to minimize the criticality of individual facilities to the network. 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.

The United States needs to develop an accessible geospatial infrastructure corresponding to, and compatible with, the nation's transportation infrastructure. The resulting geospatial information should reflect all elements of the transportation infrastructure, and include detailed information on location, structure, condition, and other attributes. 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 the operation of 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 of geospatial databases on the federal level, much more needs to be done on the state and local level to reap the 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.[12] If extended to transportation, these recommendations would under gird the U.S. transportation security.

4.3 Value of Remote Sensing for Critical Infrastructure Condition Assessment

4.3.1 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 ingested and 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 the importance of tone, texture, size, shape, and spatial arrangement in analyzing landscape features. For transportation lifelines, most applications focused on right-of-way planning, engineering cut and fill measurements, feature identification, and land use classifications for map-making purposes. The imagery was generally archived or even destroyed after its immediate use was achieved. Where these archives can be retrieved, they represent a resource for measuring the rates and directions of lifeline infrastructure growth. These images also show the 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 will be required for incident management. In short, lifeline vulnerabilities develop over time and can only be efficiently catalogued, referenced, and assessed by examining the history of imagery of an area.

Data Mining & Visualization: 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 need be), 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 Nino episodes is enhanced by daily, seasonal, and annual data mining queries of sea surface temperatures in the equatorial Pacific. Future "episodes" of El Nino are being predicted on the basis of past occurrences melded with our growing understanding of the triggering mechanisms. Mathematical techniques such as rule-based systems and fuzzy logic help the 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 can find 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, inter-modal 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, draped over a digital elevation model of the area. 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, view sheds, and related incident attributes. Visualizations can, of course, be created without image backdrops, and for some needs these may even be desirable; but for realistic, real-time, incident management, the actual ground area needs to be modeled. In the case of a hypothetical airport incident the use of high-resolution imagery could be used to provide overall situational awareness to supplement ground intelligence. Figure 1 illustrates the capability of the new quick bird II satellite system from Digital Globe that has a panchromatic resolution of 61 centimeters.

Detecting Subtle Landscape Changes: Change detection over time is one of the major advantages of remote sensing technology. 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 2 displays an image of these spots, collected by Earth Data International. 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 would be used (for such phenomena as ship wakes, contrails, cool spots left by parked vehicles), all of which represent intelligence for counter terrorism or 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. Figure 3 shows an area along the northern coast of California where seasonal subsidence occurs.

Monitoring Consequences of Incidents: Recovery from damaging incidents, natural or otherwise, is an ongoing element of security, public safety planning and infrastructure condition assessment. Relief and health officials need to know where the transportation lifelines have been disrupted, which avenues are still available for evacuation, which structures are safe, or where evacuees are beginning to congregate. Image analysis within GIS architecture can assist to develop this information. An example is the airborne imagery[14] shown in figure 4 of the condition of an interstate highway interchange following the North Ridge Earthquake in California. This data was used in the initial response phase and when integrated with other information was used as part of the recovery and reconstruction-planning phase. Digital imagery can also be used to directly assist the local condition in disaster recovery events such as the tornado damage characterization shown in figure 5. This is digital frame camera data that was used for damage assessment and emergency response following a tornado that occurred on June 1, 1998 in Mechanicsville, New York.

4.3.2 Non-Imaging Sensors

Detect Precise Object Locations at a Precise Time: The constellation of global positioning system (GPS) satellites is a well-known and widely used capability 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 adequately derived from using imagery analyzed by soft-copy photogrammetric techniques and integrated with traditional GIS datasets; but incident management may require the determination of spot locations, or to the ability to follow objects moving along lifelines. These 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 also 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 multi-spectral sensors that can be "tuned" to find specific chemical compounds in a complex atmosphere of numerous gases. Sometimes called "snifters," 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 snifters 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.

4.4 Transportation Infrastructure Threat Reduction

Transportation organizations at all levels face unprecedented challenges today. Increasing demands are being placed on agencies to preserve the existing transportation system and to take on new missions of improved system safety and security. A variety of advanced technologies are available to enhance planning, designing, managing, operating, and maintaining all modes of transportation. Aerial and satellite remote sensing represents one area of rapid development that can be leveraged to address these challenges. These technologies have significant and unique potential for application to a number of cross cutting transportation security issues.

Advances in geospatial sensors, data analysis methods and communication technology present new opportunities for users to increase productivity, reduce costs, facilitate innovation and create virtual collaborative environments for addressing the challenges of security improvement for all modes of transportation. Sensor developments include a new generation of high-resolution commercial satellites that will provide unique levels of accuracy in spatial, spectral and temporal attributes. An example is shown in figure 3 using data from the Digital Globe's commercial Quick Bird satellite to image a portion of Reagan National Airport at a spatial resolution of sixty-one centimeters. This provides a degree of detail not available previously to the civil transportation community from space based sources. In addition to the high resolution panchromatic imagery illustrated above there are a number of other commercial imagery products that are potentially applicable to transportation. They include air borne and satellite radar, LIDAR, multi-spectral, and hyper-spectral sensors. There is a range of spectral and spatial resolution capabilities for each of these sensor systems. Part of the challenge is matching the best sensor to the specific transportation related application.

Visualization and advanced data analysis methods are also important capabilities. Automated change detection within a defined sector is one example of analysis capability that will assist in detection of unauthorized intrusion events. A specific application of these techniques to transportation security is unauthorized right of way intrusion on pipeline systems. Pipelines often cover thousands of miles and are located in remote areas that are difficult and expensive to monitor. Canada is experimenting with the use of satellite imagery to assist in monitoring of pipeline rights of way to detect unauthorized intrusion onto pipeline right-of-ways in a remote area.

These geospatial technologies and data analysis capabilities can also be applied to the evolution of other new methods and approaches for enhancing the safety and security of critical transportation systems and infrastructure. The geospatial area is a family of technologies that is in transition. The speed of geospatial product delivery will continue to get faster while the cost goes down. As the use of geospatial produces increases there will be an expansion in new software tool development. There will also be continued improvement in imagery resolution and the quality of derived products. There are a number of transportation related applications of geospatial technology. These include: site assessment and investigation, monitoring critical transportation corridors, designing security systems, monitoring critical infrastructure, rapid change detection over wide areas and security data and system integration.

There remain a number of challenges that may slow or impede the application of geospatial technologies to the transportation sector. These include the need for improved methods and authorities for better data sharing across institutional boundaries. The developed and user communities need to communicate better and overcome some significant disciplinary differences. There are also some very challenging technical issues in the multi-sensor data fusion area to be overcome. Finally, there is a need for a focused interdisciplinary effort for the development of geospatial transportation priorities and the identification of specific product requirements.

5.0 CONCLUSIONS

It is clear that despite excellent efforts by many groups the approach to providing information for infrastructure condition assessment in emergencies is not effectively utilizing a wealth of data that resides, with various organizations. This existing information and technology could provide mangers important decision support products that could save lives, reduce damage to property, and lessen environmental impacts. The current situation is characterized by numerous shortcomings that inhibit optimal decision making for emergency management. The inability to access information and the lack of standardization, coordination, and communication are all obstacles that need to be overcome. In addition there are tools in the geospatial information area that could contribute immensely to infrastructure management in emergencies and in more routine operational situations. One of the ways to accomplish these aims is to make more effective and timely use of aerial and satellite surveillance and monitoring technologies. The challenge is how to adapt the existing capabilities of image-derived intelligence 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.

Advances in Information systems, satellites imaging systems and improved software technologies have led to opportunities for a new level of information products from remote sensed data. The integration of these new products into existing disaster response systems can provide a wide range of analysis tools and information products that were not possible before. For example, with the higher resolution imagery change detection for building damage assessment can be conducted rapidly and accurately with these new data sources. Transportation infrastructure and system wide situational awareness over a broad area could also be addressed using remote sensing data sources. In the area of spectral sensing new hyper-spectral sensing systems will allow detection and identification of specific surface materials, air and surface pollutants and ground vegetation types. All of these information products can be useful in the response, recovery, and rehabilitation phases of infrastructure management prepardness.

The strength of any paradigm shift is realized if new questions can be answered along with traditional ones. Using remote sensing technologies combined with information sharing will address many, if not most, traditional safety, hazards, and disaster issues facing infrastructure managers, as well as provide for those raised by deliberate acts of aggression. Despite technological advance, disaster risk continues to grow. Infrastructure emergency managers and others continue to be called on to make decisions during disaster events, as well as in the pre-and-post disaster phases, with incomplete information. In order to make optimal decisions to reduce the loss of life and property, stakeholders uniformly must be able to obtain the needed information in a format that is appropriate for their capabilities. There is also the need for parties at great distances from each other to be able to share information in a seamless fashion that also allows the shared information to be interactive with local data and be used to create new integrated products tailored to the situation.

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7.0 LIST OF TABLES AND FIGURES

System	Infrastructure	Use
Highways	210 million vehicles 4 Million miles of road 500,000 bridges (1/3 of 127,00 urban bridges serve as major arterials	4 trillion passenger miles 920 billion freight ton miles
Rail	18 million railroad cars 250 inter-city Amtrak trains 150,000 track miles	20 million passenger miles 1.3 trillion ton-miles
Aviation	175,000 aircraft 5,500 public use airports	403 million passenger miles
Waterways	12 million watercraft 25,000 miles of waterways	600 billion ton-miles of oil Plus 958 billion ton-miles of other bulk commodities
Ports	Freighters, trucks, barges, rail cars	Million per year through major U.S. ports
Pipelines	1.6 million miles	19 trillion cu. ft. of gas

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

Figure 3: Digital Globe Satellite image of Regan National Airport at 61 cm spatial resolution

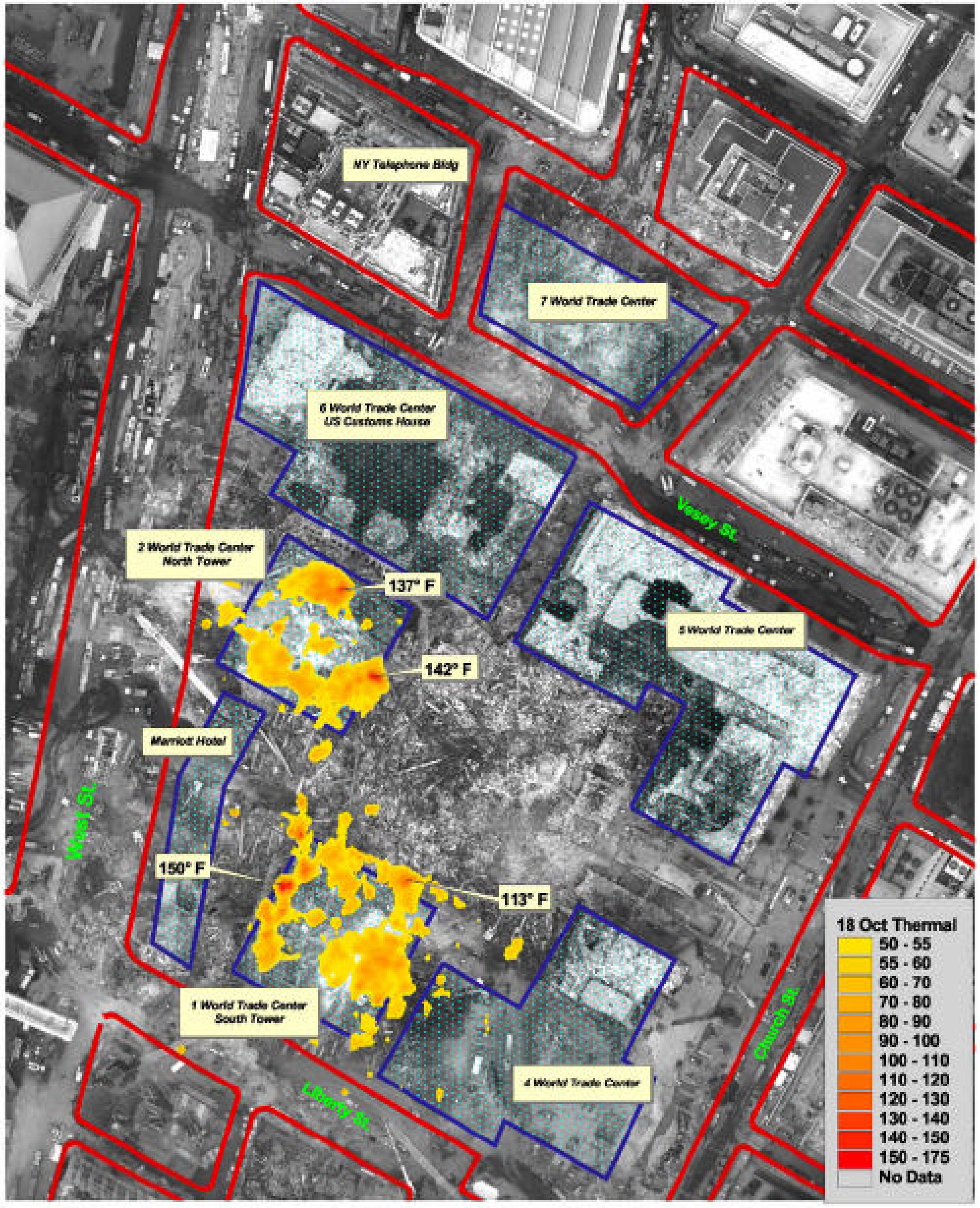

Figure 1: Image from the Multi-spectral Thermal Imaging Satellite of DOE, which was used to better understand hot spots during the World Trade Center recovery

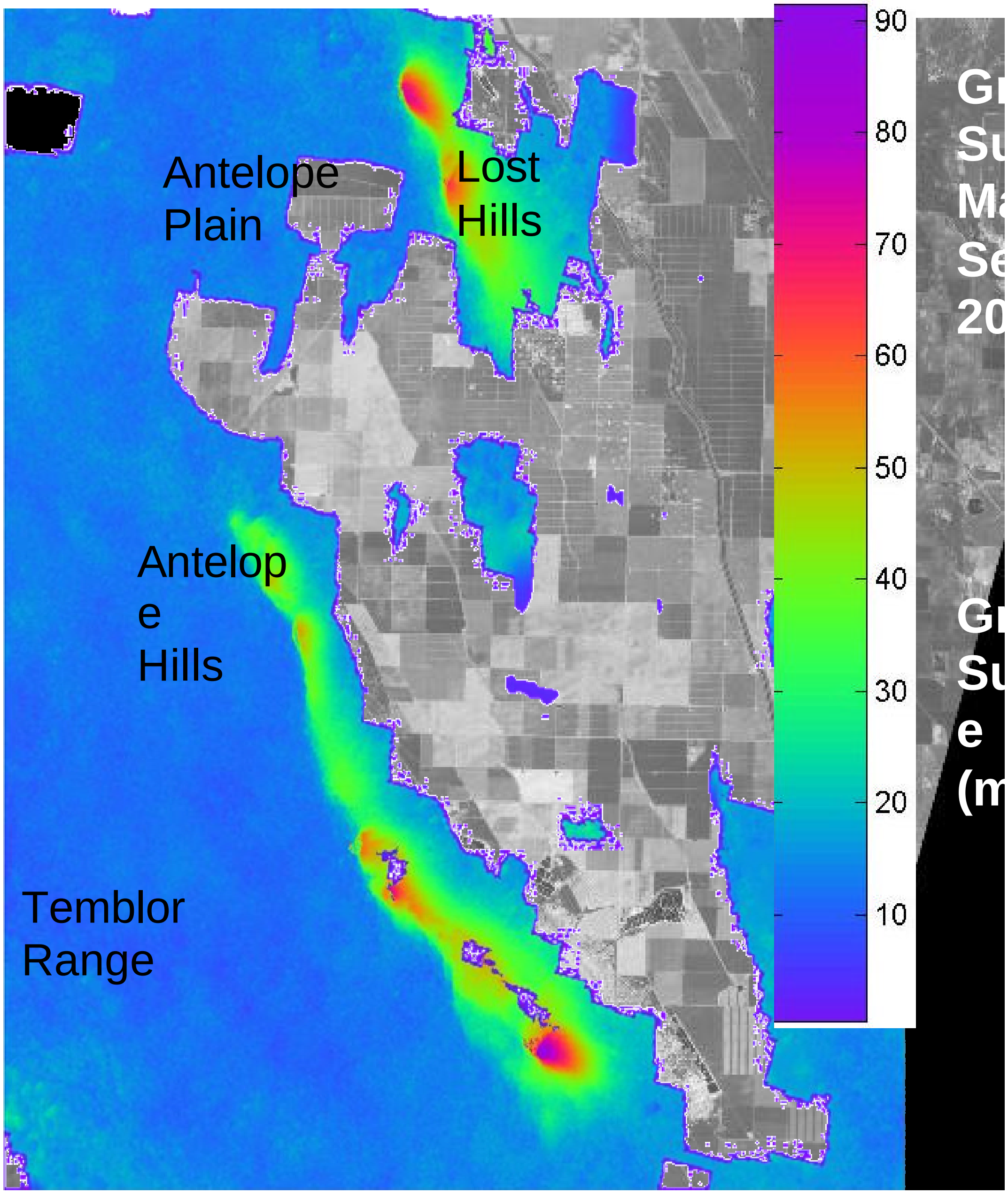

Figure 2: Illustration of interferometry to identify subsidence risk areas along the coast of northern California

Figure 4: Imagery of bridge failures following the Northridge Earthquake in California, January 22, 1994

Figure 5: Imagery used in damage assessment and recovery planning following a tornado in Mechanicsville, NY