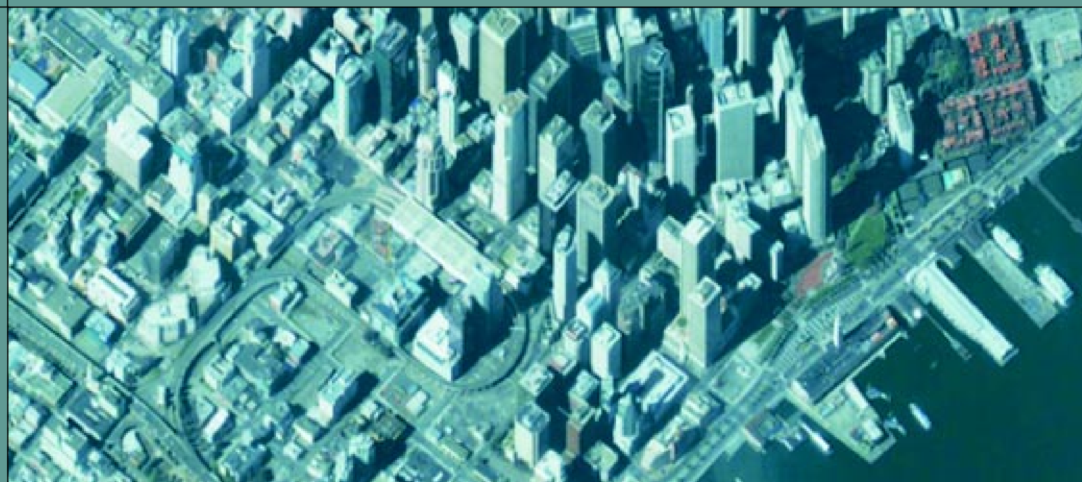
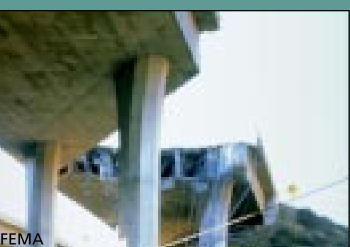
REMOTE SENSING AND SPATIAL INFORMATION TECHNOLOGIES

APPLICATION TO MULTIMODAL TRANSPORTATION

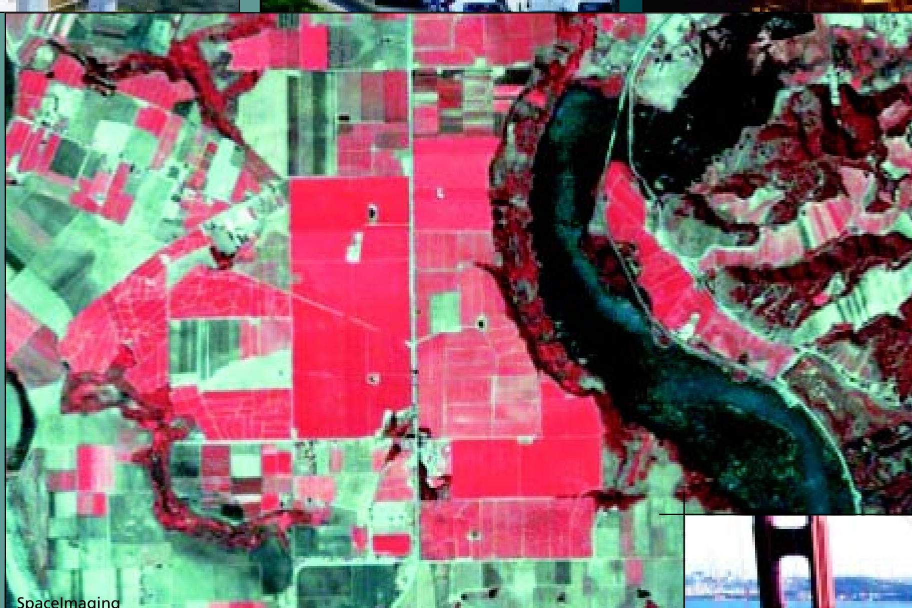


DigitalGlobe

PROGRAM ACCOMPLISHMENTS



FEMA



SpaceImaging

DEVELOPING AND IMPLEMENTING

Advances to Transportation Practice

MAY 2003

A U.S. DOT COLLABORATIVE RESEARCH PROGRAM WITH NASA

"Our nation's transportation systems face significant challenges in congestion, intermodal connectivity, freight efficiency and project delivery. Nothing has as great an impact on our economic development and quality of life as transportation."

— Secretary of Transportation, Norman Y. Mineta

"NASA's job is to develop technologies to support our mission in Earth science research, and then to turn the results loose so that government and America's entrepreneurs can shape them into products for the greater good, to serve important objectives."

— NASA Administrator, Sean O'Keefe

"The safer, smarter and simpler transportation systems in our nation's future will be an outcome of the kind of partnership and collaboration so well reflected in our joint program with NASA on the Remote Sensing and Spatial Information applications to transportation."

— RSPA Acting Administrator, Samuel G. Bonasso P.E.

U.S. DOT COLLABORATIVE RESEARCH PROGRAM WITH NASA

Bureau of Transportation Statistics	Ames Research Center
Federal Aviation Administration	Dryden Flight Research Center
Federal Highway Administration	Glenn Research Center at Lewis Field
Federal Motor Carrier Safety Administration	Jet Propulsion Laboratory
Federal Railroad Administration	Johnson Space Center
Federal Transit Administration	Kennedy Space Center
Maritime Administration	Langley Research Center
National Highway Traffic Safety Administration	George C. Marshall Space Flight Center
Research and Special Programs Administration	Goddard Space Flight Center
	John C. Stennis Space Center

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DR. K. THIRUMALAI (Executive Secretary)
Research and Special Programs Administration

Progress on Remote Sensing and Spatial Information Technologies Application Program

This report presents accomplishments from the national program on Commercial Remote Sensing and Geospatial Technology application to transportation. This program was authorized under Section 5113 of the Transportation Equity Act for the 21st Century (TEA-21) of 1998 . The program is administered by the U.S. Department of Transportation (U.S. DOT) in collaboration with the National Aeronautics and Space Administration (NASA) with a strategic focus on applying remote sensing technology for achieving smarter and more efficient transportation services, safety and security.

Four national consortia were established in partnership with universities and service providers for the program. Each consortium team was led by a major university and focused research in one priority area of technology requirement for transportation practice. The collaborative partnership program, in cooperation with state transportation agencies, has built the foundations for end-to-end development and implementation of remote sensing technology for meeting user needs in the following four priority transportation service areas:

- Faster and Cheaper Environmental Services: Streamlining multi-modal corridor planning and environmental data services for faster decision making at reduced costs.
- New Frontiers for Infrastructure Management Services: Innovative solutions for critical infrastructure asset management, and for improving maintenance service efficiency.
- Expanded Horizons for Traffic and Transportation Flow Services: New applications for regional traffic and freight flow monitoring and management by integrating remote sensing technology with Intelligent Transportation Systems (ITS).
- Robust Disaster and Emergency Assistance Services: Technology advances for improving the preparedness response of communities for unplanned disasters and security of critical transportation lifeline systems.

The results and products from the program have significant payoff for improving transportation services. The product advances also represent a significant potential for U.S. transportation technology competitiveness to reach global transportation services markets.

Program Management
Research and Special Programs Administration
Dr. K. Thirumalai, Program Manager
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Application focused consortia partnerships

ENVIRONMENTAL APPLICATIONS

Mississippi State University
University of Alabama in Huntsville
University of Mississippi
Auburn University
Universities Space Research Association
NASA Marshall Space Flight Center
Digital Globe
Intermap Technologies Corporation
Earth Data Technologies, LLC
ITRES Corporation

Virginia DOT
EarthData
ICF Consulting
Washington State DOT
Veridian Systems Division

INFRASTRUCTURE MANAGEMENT

University of California, Santa Barbara
University of Wisconsin-Madison
Iowa State University
University of Florida
Digital Geographic Research Corporation
Geographic Paradigm Computing Inc

Florida DOT
University of Massachusetts
Orbital Imaging Corporation
Tetra Tech, Inc

HAZARDS AND DISASTER MANAGEMENT

University of New Mexico
University of Utah
Oak Ridge National Laboratory
George Washington University
York University

ImageCat, Inc
DigitalGlobe
AERIS Inc

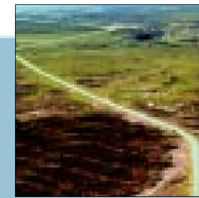
MULTIMODAL TRANSPORTATION FLOWS

The Ohio State University
George Mason University
University of Arizona

GeoData Systems Inc
TerraMetrics, Inc
Veridian
Grafton Technologies
Technology Service Corporation
Bridgewater State College

Streamlining the environmental decision process

FOR MULTIMODAL CORRIDOR PLANNING, RELOCATION AND PROJECT DELIVERY



Geospatial technologies provide new approaches for collecting data, and tools for planning transportation corridors, streamlining NEPA planning requirements, and enabling responsive decision-making on environmental issues related to transportation. The application of remote sensing and geospatial technologies shows significant promise for improving the efficiency and quality of data and information collection for the environmental permitting process, and for reducing the cost and time of completing corridor planning and assessment activities for project delivery.

Transportation corridor planning and associated environmental assessment activities are the first step before transportation projects can be conducted and important transportation services initiated and delivered to the public. Determining and mitigating transportation project impacts is part of a process that fully involves resource agencies and the public in the decision process for ensuring that the project minimizes adverse impacts to the environment.

NCRST research is focusing on how remote sensing and spatial information technologies lead to timely collection of high resolution remotely sensed data that can be used to shorten decision making in various stages of transportation project life cycles including the preliminary planning and environmental assessment phases. The application has the potential for significantly reducing the time needed for assessment of alternatives, before design activities take place. Appropriate acquisition and application of remotely sensed data and geospatial technologies can help planners to project and assess environmental problems "upstream" in the planning process so that consequences are considered and accounted for early in the process for speeding project delivery.

Studies have been conducted that illustrate how the acquisition of LIDAR data early in a project can improve planning and preliminary design activities, as well as improve hydrologic and wetland analyses and cut-and-fill estimations. NCRST researchers applied high-resolution image to classify sensitive vegetation and habitat areas, as well as to indicate areas where transportation and land use development have occurred in the vicinity of sensitive habitat areas. A variety of remote sensing data have been used to develop algorithms and tools for improving efficiencies in various environmental analysis and corridor planning tasks. These early results are being applied by NCRST researchers to support a landmark project for completing Environmental Impact Statement (EIS) on options to relocate existing gulf coast CSX rail lines away from coastal townships.

Automated tools for optimum corridor planning

An Automatic Road Planning Tool was demonstrated by an NCRST Technology Application Partner (TAP) to the Maine Department of Transportation (ME DOT) during an ongoing ME DOT corridor planning project. This software was based on optimal path planning algorithms that were originally developed by TSC for ground vehicle tracking.

The software utilizes freely available USGS DTED and the National Land Cover Database to select the best route for new road construction. The automatically selected route is overlayed on high resolution Ikonos satellite imagery for the user to define and avoid exclusion zones that include wetlands and other protected resources. The road costs that are minimized include land acquisition, earthworks, existing road upgrades and new bridge/road construction. The PC-based tool also provides a 3-D stereo view of the terrain that allows users to better visualize elevation and includes graphical interfaces to specify various road cost factors.

During this effort, the TAP was partnered with the ME DOT to recommend and evaluate alternative routes for an I-395/Route 9 connector project near Bangor/Brewer, Maine. As a final step in the effort, the TAP demonstrated the Automatic Road Planning Tool to ME DOT analysts who had used traditional manual methods to identify families of corridors for this connector. The automatically selected route was in close agreement with the baseline corridor. However, the Ikonos imagery overlay indicated that the route traversed close to an established suburban development that was opposed to the new route. When this region was excluded, the tool automatically produced an alternative route that agreed with another one of the manually selected corridors.

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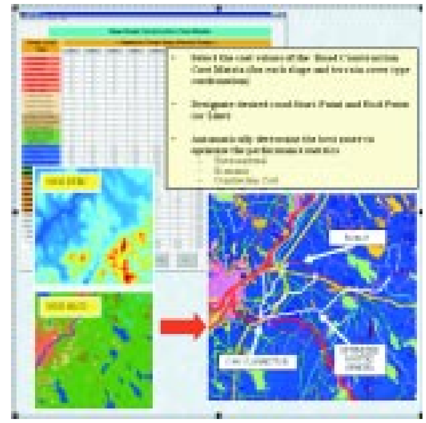

Figure 1. Example of best route for new road construction using the Automatic Road Planning.

Streamlined data collection for relocating the CSX railroad in the environmentally-sensitive Mississippi coastal corridor

An environmental impact study is being conducted to assess the impacts of relocating segments of the CSX railroad out of significant population growth areas along the environmentally sensitive Mississippi Gulf Coast. The environmental assessment project, which is jointly managed by the Mississippi DOT and FHWA, is making broad use of remote sensing and geospatial technologies. The project will be the first ever to make extensive use of remote sensing and geospatial technologies to conduct an EIS. The project will provide the first opportunity (for a study of this kind) to measure the improvements in the EIS process made possible through the integration of remote sensing and spatial technologies. The outcome of the project should result in improved knowledge about how to appropriately use remote sensing and spatial technologies to increase the efficiency of planners, shorten project timelines, and decrease overall costs.

Anthropogenic activity of the past three decades along the Mississippi Gulf Coast has resulted in significant changes in land use, demographics, socio-economic conditions, and environmental stability. During this 30-year time, US Interstate 10 (I-10) has been completed, extensive population growth has occurred, and the coastal counties have changed from being mostly small fishing communities to a complex mixture of residential, commercial and industrial urban areas with a robust tourism industry due to the onset of a large casino-gaming industry in the early 1990's. These changes have resulted in a diverse landscape with protected unspoiled coastal wilderness areas intermixed with active urban areas and booming port-based industries.

Currently, the CSX railroad runs through business, tourism and population centers along the Mississippi Gulf Coast. While intermodal transportation is critical to the regional economy, the railroad in its current location causes significant community and railroad conflicts, causes significant traffic delays, poses a safety risk for at-grade crossing, is an impediment to area evacuation during natural disasters, and poses a threat to the area in the event of a rail accident. A rail relocation and corridor planning study is underway in the area to resolve these problems and seek to find a solution to relocate the railroad and intermodal connectors, provide effective intermodal connectors, improve the economic competitiveness of the region and the commercial capacity of the corridor, provide improved port access to freight, provide more efficient intermodal transportation resources for the corridor, and reduce grade crossing by optimizing the relocation of the railroad and by making effective use of grade separation strategies.

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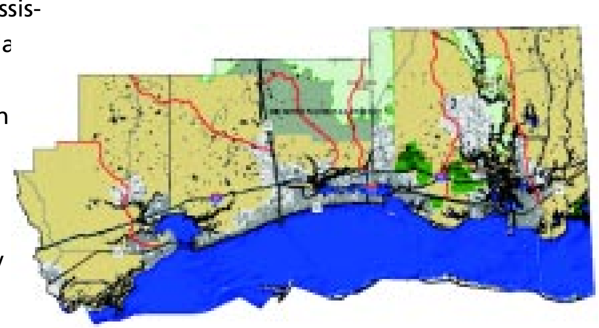

Figure 1. Mississippi Gulf Coast counties showing major transportation features, cities, parks, forests, wildlife management areas, and known environmental sensitive features.

Assessing urban growth and transportation-related development in complex coastal environmental areas

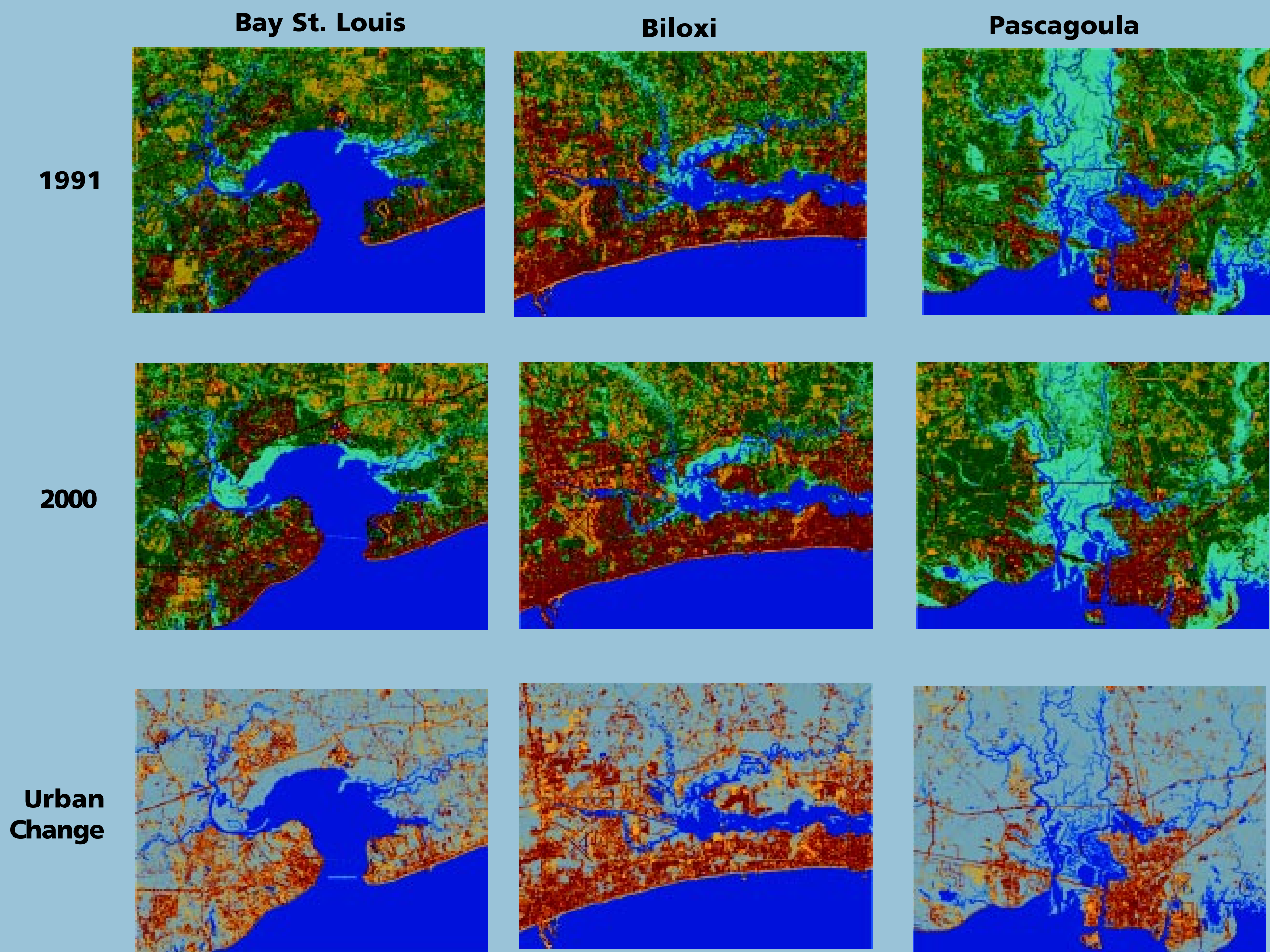

Figure 1. Change in LULC and growth in urban areas near the cities of Bay St. Louis, Biloxi, and Pascagoula, Mississippi. Changes can be seen by comparing the red urban areas in the 1991 images against the red areas in the 2000 images. The urban change images summarize urban growth by showing areas that were urban in red (1991) and areas of growth in yellow (2000).

NCRST research on the application of remote sensing and geospatial technologies to transportation planning and environmental assessment has led to the development of a methodology to provide accurate, dependable land use and land cover (LULC) classifications in urban areas located in coastal zones. The LULC classification methodology provides significant accuracy improvements over synoptic approaches via data and information processing methods that employ knowledge management, phenologic change, and formal rule-based classification using a thematic change logic table. The new method proves to be quick and accurate, and produces highly useful and manageable products for analysis, planning, and mapping.

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Assessing environmental impacts of land cover and socioeconomic changes at the watershed scale

Development of transportation networks can cause significant changes in the land cover, socioeconomic dynamics and demographic breakdowns of populations within a given area. These human factors can in turn impact the environment at spatial scales ranging from local to watershed level to regional. In this project, environmental impacts were evaluated at the small watershed scale by analyzing the relationships between these anthropogenic factors and hydrologic indices. The hydrologic indices selected were mean annual flow, frequency of inundation above specified levels, and corresponding duration of inundation. These indices were selected due to their close relationship with environmental issues, such as wetlands identification, habitat maintenance, and floodplain analysis. The study focuses on two small urban watersheds in the metropolitan Atlanta, Georgia area (Sope Creek and Big Creek).

Streamflow records obtained from the U.S. Geological Survey demonstrate that since the late 1980's mean streamflow in Big Creek has increased by roughly 60%. This period corresponds approximately with the dramatic increase in population and associated commercial activity in this basin. The increase in residential and commercial development in the watershed has led to significant increases in impervious area and improvements in the drainage network that tend to increase the peak runoff rates draining from the basin.

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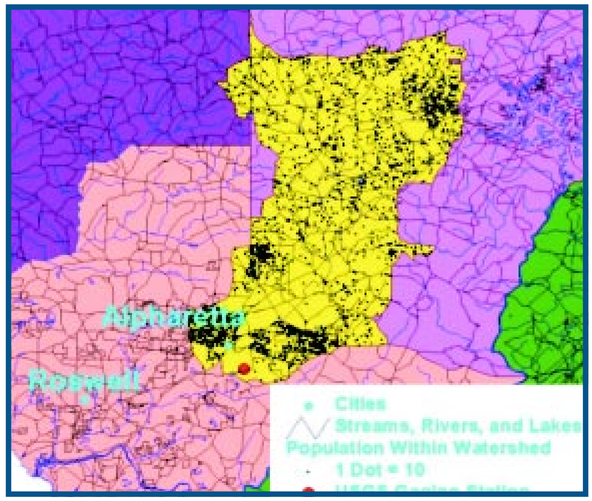


Figure 1. Site location of Big Creek Watershed.

Figure 2. Population increase in Big Creek Watershed (1965-1998).

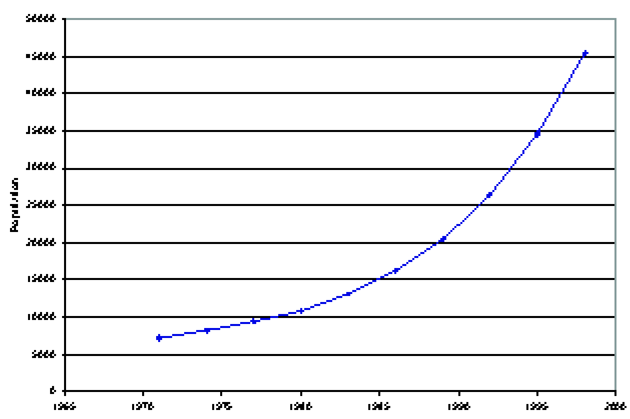
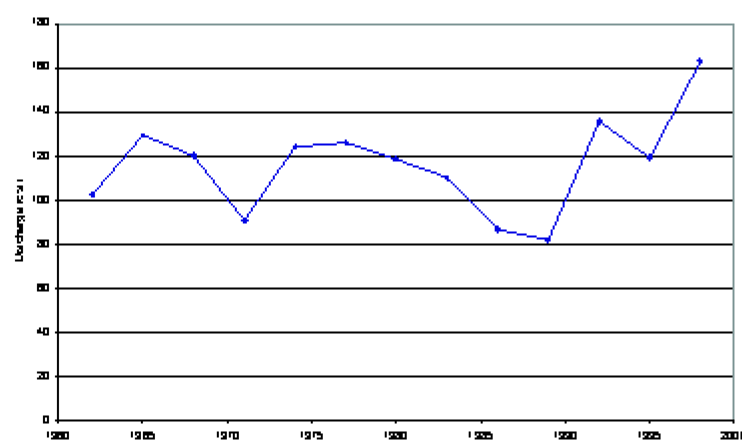


Figure 3. Running three-year average flow for Big Creek Watershed (1960-1998).



Application of remote sensing technologies for planning and maintaining pipeline corridors

Safe pipeline transportation of energy resources is a major concern for the public. Geologic hazards, corrosion, and third-party damages pose cumulative internal and environmental risks to pipeline integrity. Pipeline owners and operators are under pressure to produce accurate maps of pipeline routes. Pipeline engineering and operations are increasingly reliant on collecting and analyzing geospatial data for safety throughout a pipeline's life cycle of design, construction, operation, maintenance, emergency response and post-disaster restoration.

Rapid and affordable acquisition of physical and ecological data along the pipeline corridor are critical for analyzing risks. Remote sensing technologies help identify risks to pipelines and provide cost-effective management solutions. Fusing sensor data with traditional datasets provides new toolsets for pipeline managers and operators. High-resolution imagery and LIDAR data are two types of data that have been tested for use in planning and monitoring pipeline corridors.

In California, high spatial resolution images are used to assess natural hazards within a pipeline corridor near Cordelia, a community in the San Francisco Bay Area. Pacific Gas & Electric Co., managers of the pipeline, combined the imagery with other spatial datasets to create base maps for risk assessment along the pipeline corridor. In addition, biomass measurements, maps of geomorphology, and geological data can be merged with pipeline engineering datasets and satellite imagery within a 1-km corridor to produce a toolset for use by pipeline systems operators, maintenance managers and decision makers.

One of the products developed for this application is *Image Proc*, which is a set of software tools that extracts shape information from images for change detection analysis. Another product is a numerical model called *Pipe* that predicts the probability of pipeline failure caused by natural hazards. Other bi-products include a spectral library of pipeline physical and ecological hazards, thematic maps of features correlated with pipeline failure occurrences, and an integrated database that supports decision-making by providing predictions of direct economic effects.

LIDAR data offer another effective solution for assisting managers in pipeline risk analysis. Airborne LIDAR is an aircraft-mounted laser designed to measure the 3-D coordinates of the Earth's surface. LIDAR is an effective technology for acquiring accurate terrain surface data along transportation corridors. It is easy to obtain many terrain parameters and to generate 3-D fly-throughs using these data. Since LIDAR systems have a narrower swath in comparison to optical sensors, they can often capture corridor-based information more cost-effectively.

There are two tool sets available for processing and visualizing LIDAR data for applications in pipeline corridor risk management. *LIDAR Analyst* is a software tool for processing airborne LIDAR data. The tool set supports (a) automated generation of bare-earth DEMs from

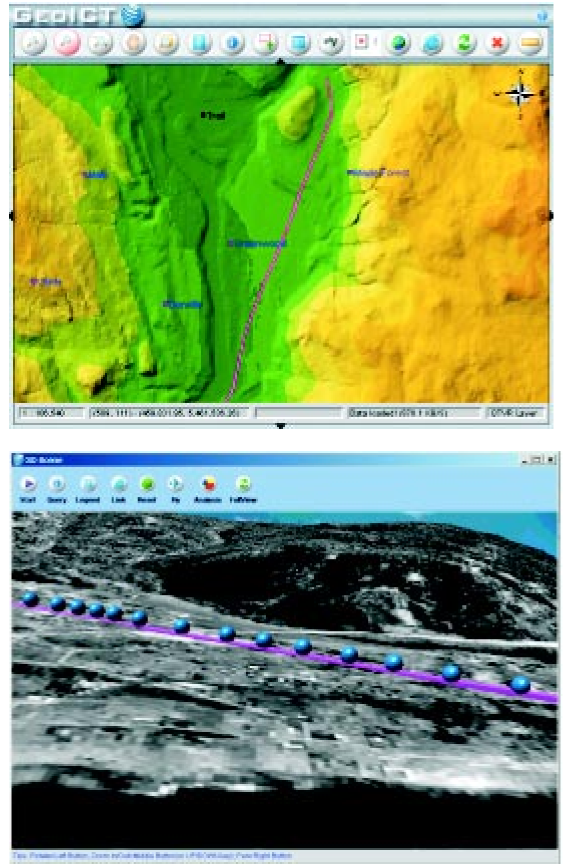


Figure 1. GeoServNet *visualization tool used for routing pipelines. Views are presented as 2-D (top) or as 3-D (bottom).*

raw LIDAR point clouds; (b) automated removal of vegetation from raw LIDAR data; (c) generation of terrain drainage networks and biomass parameters; and (d) automated reconstruction of features, such as buildings and road networks. GeoServNet v1.5 is a web-based 3-D visualization tool for distributing and visualizing large amounts of spatial data, particularly DEMs and images, over the Internet. It is a breakthrough technology, as it is the first of its kind to deliver 3-D GIS modeling and analysis over the Internet.

Products generated for pipeline managers include terrain parameters, biomass estimates, tree type identification, tree height and density estimates, watershed identification, drainage network identification, and bare-earth digital elevation models.

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LIDAR measurements of air pollutants and air quality modeling related to highway traffic

The primary objectives of an NCRST air quality project are: (1) the development of a technology guide on the use of remote sensing – DIAL (Differential Absorption LIDAR - Light Detection And Ranging) for real-time measurement of air pollution resulting from highway traffic, and (2) an air quality model for prediction of air pollution considering the impact of highway traffic, land use, terrain type and climatic factors.

To safeguard the public health, the Environmental Protection Agency (EPA) has developed threshold standard concentration levels of tropospheric or ground-level ozone (O_3), nitrogen oxides (NO_x), carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM), and sulfur dioxide (SO_2). Significant air pollution comes from coal-fired power generating plants (PM, CO_2, CO, and NO_x) and vehicle emissions, particularly volatile organic compounds (VOC) or hydrocarbons, CO, and NO_x. Other sources include industries, railroad, aviation, fires and natural emitters. Recent studies and congressional testimonies show that some of these pollutants may be linked to respiratory problems and lung diseases, especially in the high-risk groups of young children and senior citizens.

Non-invasive remote sensing DIAL technology allows real-time in situ measurements of NO_2, O_3 and several other air pollutants in the atmosphere over long path lengths, which is ideal for transportation corridors. The laser is tuned between ultraviolet, visible, near infrared, and thermal infrared spectral regions. The difference in the absorption of light at these different wavelengths can be used to determine the concentration of air pollutants (Figure 1). The remote sensing DIAL measurements are more representative of actual volume-averaged concentration than the point monitoring method, which depends upon the collection of air samples in specialized bottles/canisters for post-sampling and laboratory analysis. A state-of-the-art tunable DIAL technology guide has been developed that includes measurement protocols for NO_2 and O_3 with applications in Oxford and Tupelo, Mississippi. A database of air pollution, traffic and climatic parameters has been created for selected cities. The database is being used to develop an air quality model to consider the impact of highway corridors on air pollution concentration and dispersion.

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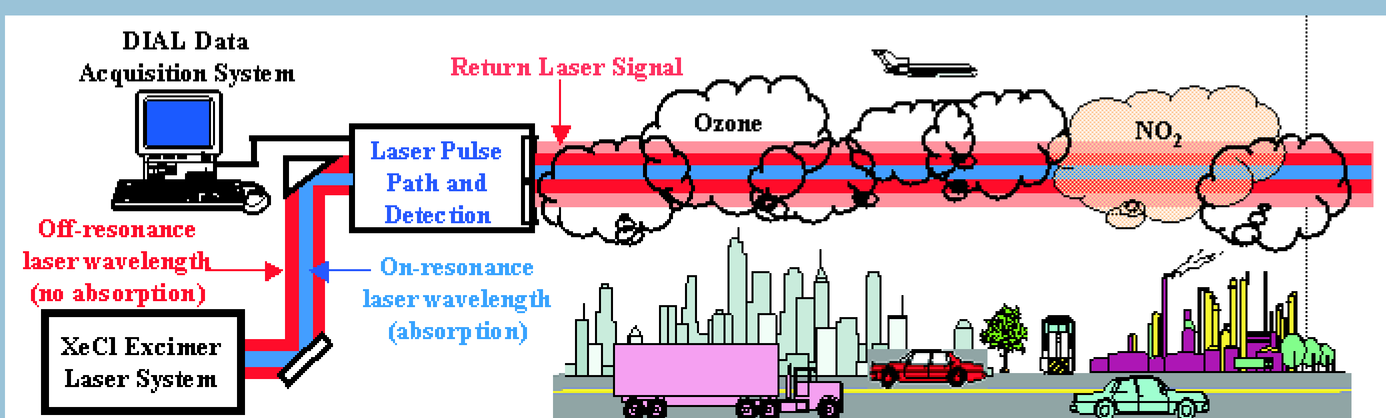

Figure 1. Principle of DIAL technology for measuring air pollution.

New Frontiers
for smarter infrastructure
ASSET MANAGEMENT AND SAFETY

Remote sensing and spatial information technologies offer a variety of new tools for reducing delays, improving infrastructure maintenance and management services, and for maintaining accurate inventories and valuations of assets. Remote sensing technology applications have the potential to deliver faster, more accurate and less expensive techniques to survey undeveloped terrain, to assess inventory, and to record location and condition of assets on a regional and local scale, and to address security concerns related to protecting transportation services.

On the ground, geo-referenced video-logging systems are now in use by numerous states. Lasers evaluate pavement condition and report the precise location at which problems exist. Object recognition technology detects signage, measures sign height and shoulder width, and populates databases automatically. Because this can be done using vehicles traveling at highway speed, potential dangers to roadside survey crews are eliminated. Airborne and satellite imaging offer additional advantages. Several DOTs already use grayscale aerial photography and photogrammetric analysis for a number of survey tasks. LIDAR is a new technology, which is gaining rapid adoption by state agencies.

NCRST teams have performed landmark studies in applications of LIDAR, perfecting the flight navigation process, and comparing performance (accuracy, costs and benefits) against that of photogrammetry. These studies pave the way for state DOTs to adopt this new technology for accelerating project delivery. NCRST teams have also made significant advances in the science of detecting physical characteristics of roads from satellite and aerial imagery for distinguishing pavement structures. A visual tool has been developed for bridge identification — DOTs can now examine the accuracy of bridge locations in the National Bridge Inventory (NBI) and amend them as required. Intermodal connections and changes in land use have been surveyed from imagery, in Boston and Los Angeles.

In order to assess infrastructure adequacy and security, NCRST teams have created traffic micro-simulation support systems and are analyzing the resilience of transportation systems. Finally there is a need to simplify the complexity of image analysis, data modeling, reduction, cataloging and indexing, to support advances in imaging and image processing. NCRST researchers continue to work in cooperation with states and the private sector, automating the production of maps from GPS, developing data models for transportation, and developing push-button solutions for creating transportation databases and accessing geographic information

Urban hyperspectral sensing and road mapping

Remote sensing of transportation infrastructure in urban areas is far more challenging than in rural areas, because of the variety of land cover materials with which a given target can be confused. For example, road asphalt appears very much like composite roof shingles, even under 224-band hyperspectral resolution.

To facilitate positive identification of surfaces, such as concrete and asphalt, NCRST investigators developed an extensive library of urban spectra: roads, parking lots, tennis courts and concrete roofs, striping paints, roof shingles and principal vegetative types. Even at the higher spatial resolutions of hyperspectral data available today (e.g. 4 m from the Jet Propulsion Laboratory [JPL] AVIRIS), many pixels are heterogeneous, their signatures being mixtures of those of the component materials. This research focused on isolating the extremes or “end-members” in the material set and studying their spectral separability.

Road detection even from AVIRIS data is only somewhat successful in urban areas. Success in road delineation might be improved by using additional context information, as provided by object-oriented image classification, especially since the spectral separability of different road surface materials is fairly high.

The hyperspectral approach should be simpler and more successful in rural areas because pavement signatures are less prone to confusion with those of surrounding materials. Field surveys are not cost effective in rural areas; this strengthens the argument for remote sensing.

The research provided interesting results on the effect of surface condition and age on the spectral characteristics of roads. It is possible to describe general pavement age and specific surface defects such as raveling, and to estimate their spatial characteristics from AVIRIS. Other common pavement quality parameters (e.g., rutting, cracking), however, were found to be undetectable at the AVIRIS resolution of 4 m.

Because hyperspectral systems like AVIRIS (currently an experimental sensor), are complex and too expensive for most agencies at present, this research generalized the problem to the multispectral level for general application, while addressing the science of material discrimination at the more rigorous 224-band hyperspectral level. Today's multispectral systems show significant spectral limitations in mapping road infrastructure within the urban environment. Due to the location of their spectral bands and their broadband character, their data are insufficient to resolve the distinct spectral characteristics of urban materials and land cover types. This research shows that there is a potential future for a multispectral sensor designed for use in urban and pavement mapping that would allow successful urban mapping at a large scale and an affordable price.

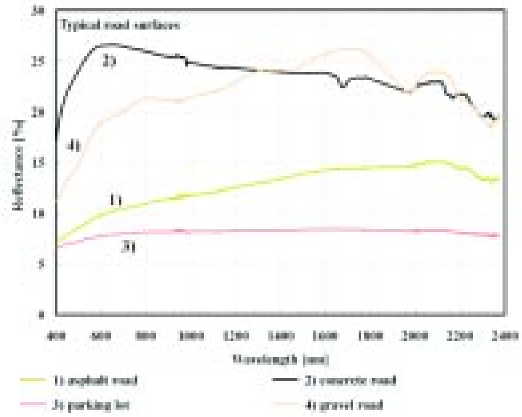

Figure 1. Hyperspectral signatures of typical road surfaces

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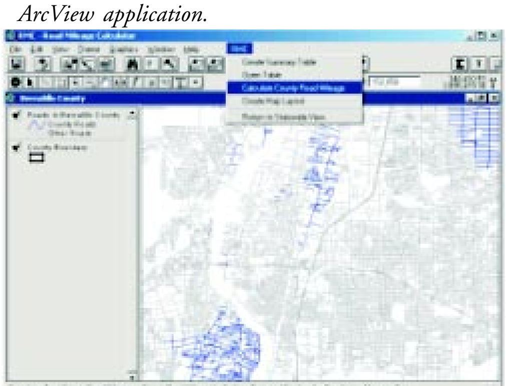
Calculating mileages for highway performance monitoring for FHWA

Compliance with the Federal Highway Administration (FHWA) Highway Performance Monitoring Systems requires all states to provide annual information on the total public road length in the state. In support of the New Mexico State Highway and Transportation Department's (NMSHTD) Certified County Road Mileage Program, NCRST produced the Road Mileage Calculator (RMC).

Figure 1. Road Mileage Calculator is a customized ArcView application.



The performance information required by FHWA includes travel, length, and lane miles for all public roads. RMC compiles mileages from digital data sources and is used by the NMSHTD to verify and validate road mileages reported by counties for submission to the FHWA.

Since these data are used to apportion funds, their accuracy is vital. RMC allows NMSHTD to identify and calculate the number and mileages of county roads. The database also includes street names and information on road surface types to assist in maintenance planning.

RMC is a customized GIS ArcView application that allows users to view and query digital data related to roads maintained by counties to produce a summary table of those data, and to print maps showing the road network (Figure 1). Data input sources include Emergency 911 (E-911) road maps that are updated using high-resolution satellite imagery.

A program for updating E-911 base road maps using high resolution satellite imagery has been implemented. These data facilitated map updates by providing a consistent, spatially-referenced image against which mapped roads are compared or extracted.

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LIDAR applications for highway design and construction

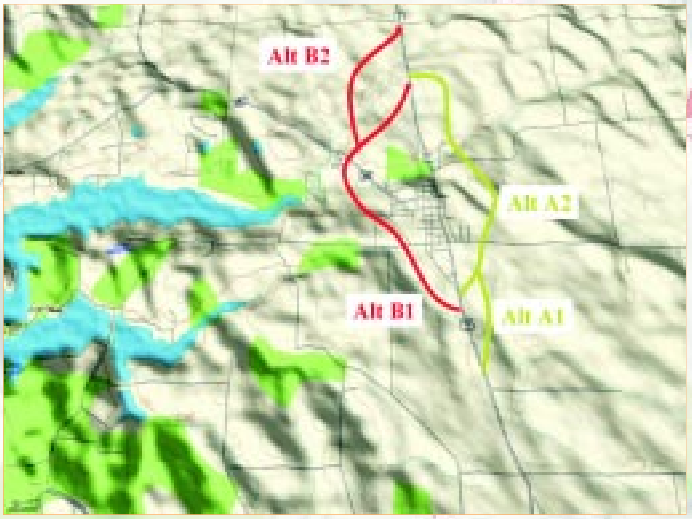

Figure 1. Highway alignment alternatives evaluated with the help of a LIDAR-derived surface model.

Highway corridor development is a lengthy process, requiring seven to ten years or more for complex projects. In response to public demand, highway agencies strive to reduce the length of this process while improving sensitivity to social and environmental concerns.

Terrain data are required for location planning, preliminary and final design. Current methods of acquiring terrain models are based on photogrammetric methods and supplemented by field survey in the final stages. The photogrammetric process requires aerial photography taken during leaf-off, high sun angle time periods (generally spring in the northern climates), as well as many hours of processing time to georeference and triangulate imagery to compute elevation values, and is therefore often on the critical path to project planning and design. The conventional photogrammetric process can take 24 months to complete.

Further, wide corridors are defined to meet Federal mandates of providing materially different alternatives for study in environmental assessment. Developing photogrammetric products for the entire wide corridor is expensive and time consuming, but facilitates rapid decision making in later stages of the development process, if alternative alignments are specified for study. This additional expense is tolerated in the interest of project schedule.

LIDAR is a relatively new technology capable of rapidly and cost effectively developing precise terrain models from an airborne platform. LIDAR faces no seasonal constraint of sun angle as it utilizes an active sensor. Under some conditions, LIDAR can also penetrate vegetative canopy, producing bald earth terrain models, which are required for earthwork computations and final design. LIDAR terrain products can be completed in less time and at lower cost than conventional photogrammetry. However, manual effort is still required to filter cultural and some vegetative features effectively. Vertical accuracy is somewhat lower than can be achieved by photogrammetry, limiting the utility of the LIDAR terrain model for final design.

This research tested the accuracy of LIDAR for various surfaces of interest to highway planners and design engineers, including sloped surfaces such as ditches and rolling terrain, hard surfaces such as roads, and vegetated areas such as crop fields and forests. The research also evaluated the ability of the commercial LIDAR product to provide a bald earth model of the land (removal of buildings, vegetation). Results indicate that as of now, LIDAR cannot completely replace photogrammetry for the entire project development process, due to accuracy limitations and inability to precisely define edges (ridges or breaklines). However, it can be used effectively in combination with photogrammetry to reduce cost and to provide more timely terrain models for an entire corridor. With LIDAR, terrain models are available much sooner in the process and LIDAR-derived terrain models can be used to refine corridor limits. If aerial photos are collected early in the development process, smaller amounts of high accuracy photogrammetric products, supplemented by field survey, can be developed in later stages, as specifically required by design engineers. Potential savings in cost and time were estimated for a typical project to be $250,000 (50%) and 11 months (45%) for project development.

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LIDAR applications for engineering design

As LIDAR is a relatively new spatial technology, standard procedures have not been developed to yield data with predictable accuracy comparable to current photogrammetric technologies. As a result, LIDAR has not been readily adopted by state DOTs for engineering design surveys. State DOT participants at NCRST-based remote sensing conferences have recommended further research into airborne remote sensing technologies (e.g. LIDAR), with particular reference to accuracy, comparison with existing technologies, benefits, data fusion, and potential applications.

With data provided by Iowa DOT, NCRST investigators compared LIDAR data with data from traditional photogrammetric technologies for a highway evaluation corridor in eastern Iowa. Elevation surfaces derived from analytical plotters, LIDAR and automatically extracted points from digital aerial photography were compared for large-scale and small-scale areas of mixed land use.

Research results provided an initial assessment of LIDAR and an assessment of digital photogrammetric data compared with LIDAR. Preliminary results indicated that for small areas, differences between LIDAR and manual data agree with vendor-quoted elevation accuracies (i.e. 10–15 cm, or ~6 in). Results also indicated

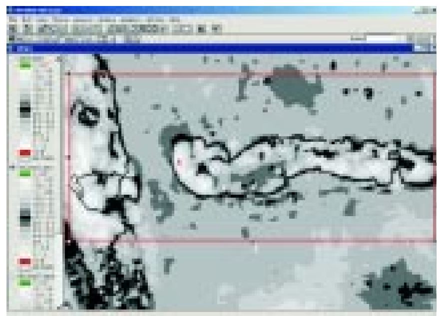

Figure 2. Elevation difference surfaces between LIDAR and manual data for gully show definition of gully and roadway (black areas indicate smaller elevation differences).

that elevations from automated surface extraction methods are as good as, if not better than LIDAR-generated elevations, compared with manual photogrammetric data. Additionally, difference variability tended to be lower using automated extraction methods than using LIDAR for all comparison regions. Finally, preliminary results showed a correlation in elevation differences with land use, but no correlation with feature type.

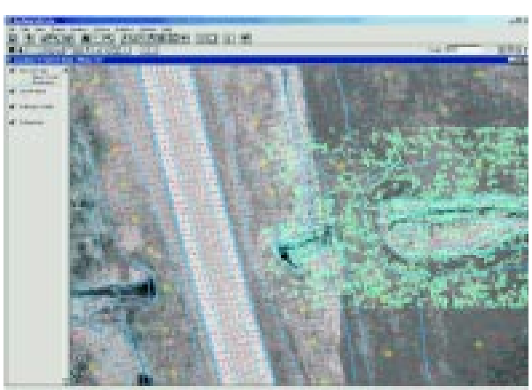

Figure 1. Orthophoto of gully with LIDAR (red), softcopy (cyan) and manual (yellow/blue) points.

These results are being used to investigate blending automated photogrammetric techniques and LIDAR for production of low cost, engineering design-level elevation data. Initial results indicate that

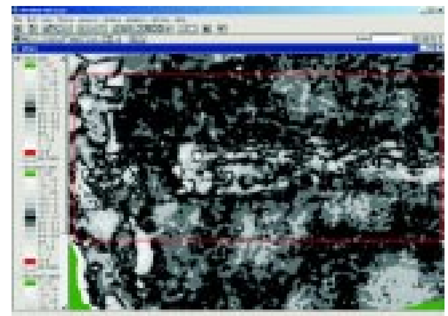

Figure 3. Elevation difference surfaces between softcopy and manual data for gully indicate smaller variation.

LIDAR-enhanced automated extraction techniques can produce elevation data closer to manual methods with less variability than using LIDAR or automated extraction alone. Using LIDAR as an initial approximation for digital photogrammetric matching, the number of failed matches should be considerably reduced, thereby minimizing required manual editing time, a significant cost factor. Additionally, these enhanced automated extraction methods can be used to fill in LIDAR gaps at comparable accuracies, allowing agencies to specify greater LIDAR point spacing at a cost savings.

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Application to planning of off-port intermodal inspection facilities

An NCRST-sponsored Technology Application Partner (TAP) research team, including the Jet Propulsion Laboratory and the NAFTA Corridor Institute (NCI), assessed transportation and land use along the Alameda Corridor and Los Angeles ports complex. Now, new imagery analysis tools developed in that project are being used to assess siting criteria for secure, off-port, multi-agency freight inspection facilities.

The initial feasibility studies were conducted through team member NCI, a freight-related research institute. NCI had developed concepts for a high technology freight inspection facility to be located at the California/Mexico border. The TAP team is now working to identify sites for such a facility in close proximity to the borders of the Ports of Los Angeles and Long Beach.

The remote sensing imagery developed for the original RSPA project has proven extremely valuable for the new facility siting project. Ikonos 1-m black & white and 4-m color imagery were merged using a JPL-developed process called Intensity Hue Saturation (IHS). This created 1-m resolution color imagery, which then was used with the Feature Analyst software for applications such as sorting stacks of containers and differentiating rooftops.

Figure 1. Carson intermodal connection yards. Pan-simulated IKONOS RGB.

Siting of a secure, multi-agency freight inspection facility is extremely complex. The present concept facility would handle as many as 1,000 trucks per day. Consequently, a site as large as 60-ac may be necessary. In a dense urban environment, such as South Los Angeles, such sites are difficult to find.

BridgeView – a new tool for bridge inventory and assessment

The Federal Highway Administration (FHWA) has mandated that each state DOT determine accurate spatial locations for all bridges maintained in its jurisdiction. Locations are stored and reported to FHWA through the National Bridge Inventory (NBI) database. State DOTs typically have some spatial data of their bridges, but few meet NBI's ± 2 m accuracy requirement. Ground-based technologies, such as GPS, can provide greater accuracies but require fieldwork, which is time consuming and expensive.

An alternative to locating bridges in the field is by using remote sensing data and digital image processing. With assistance by Wisconsin DOT, NCRST researchers developed a prototype software toolset dubbed "BridgeView." This toolset allows users to verify and update bridge locations through visual interpretation of aerial orthophoto images and satellite imagery in a desktop GIS environment (i.e., ESRI's ArcGIS®). In particular BridgeView contains tools for image management, bridge location and editing, coordinate display, and coordinate export compatible with ASCII and ESRI's UNETRANS transportation-based data model.

Given existing inexpensive and available remote sensing data, BridgeView can be used by state DOTs as a cost-saving option to reduce fieldwork. Depending on image resolution and nominal scale, BridgeView can yield bridge locations within a horizontal error of 1-2 m, compliant with NBI accuracy specifications. Since its initial release, BridgeView has generated significant interest in several state DOTs, not only for its applicability in reducing on-site bridge spatial data collection, but as tools for spatial data quality control and for transportation-based asset management systems.

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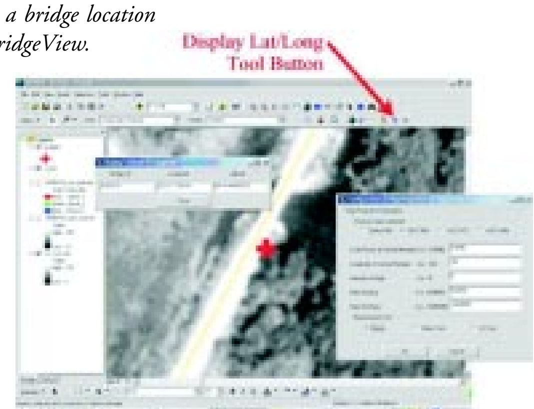
Figure 1. Example output showing a bridge location using BridgeView.



Therefore, the land use consultant for the team has been using the enhanced imagery in conjunction with an area-wide GIS to identify properties, or combinations of properties, of sufficient size to accommodate such a facility.

Land use surrounding the facility will also be an important planning consideration. Such parameters will include proximity to residential, transportation, utility, and other land uses. In an emergency situation, the secure facility might require isolation from transportation systems. Therefore, a location within a heavily industrialized area with good surface street access to the site would be optimum. The Ikonos imagery has proven particularly valuable in these site selection criteria.

Once the candidate sites have been identified, access to them is a key consideration. Freight will be diverted to the inspection facility from many terminals at the Ports of Los Angeles and Long Beach. For transportation system analysis related to the transfer of these containers, the NCRST TAP team, in association with the Southern California Association of Governments (SCAG), will extract and analyze road networks using the enhanced Ikonos imagery. Road condition, intersection analysis, throughput and surrounding land use can be assessed for road networks being considered for freight throughput.

Given the excellent resolution of the enhanced Ikonos imagery, the sites chosen for the secure facility can be integrated into a 3-D architectural design software program. Various configurations for site layout can thus be undertaken in a very cost-effective way.

As candidate sites for these secure multi-agency freight facilities are chosen and tested, a methodology will be refined, which can be applied at ports nationally. The team will also continue to integrate other imagery types into the program to improve the facility siting and design process.

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Managing rural roads in local agencies and on Indian reservations

Unimproved and graded dirt roads serve as critical lifelines to millions of rural Americans throughout the western U.S. The improvement and maintenance of these roads presents difficult challenges to state and local governments.

NCRST researchers working with personnel in McKinley County, New Mexico and the Hopi Tribe in Arizona, have produced programs that facilitate monitoring, maintenance planning, and hazard assessment for the thousands of miles of dirt roads serving the needs of rural residents in the American Southwest.

Severe weather and flash flooding pose significant problems of accessibility for residents and emergency services personnel, and cost millions of dollars in road maintenance and lost commerce (Figure 1).

Active, near real-time monitoring of weather and flood conditions and their impact on rural roads provides timely, and sometimes vital information to residents, and emergency and road maintenance services. Remote sensing information provides data for assessing weather-related road hazards and managing rural road networks.

NCRST, in cooperation with McKinley County, New Mexico, implemented an online program providing near real-time weather monitoring and road condition assessment. The Weather-Related Road Hazards Assessment and Monitoring System (WRRHAMS) provides online infor-

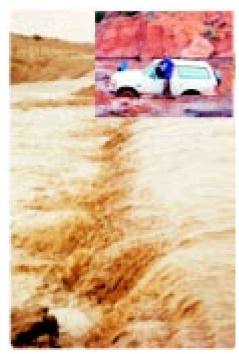

Figure 1. Flash floods in the arid southwestern U.S. can wash out roads in a matter of seconds, stranding motorists.

Figure 2. Online road maintenance decision support system for weather-related hazards on rural roads in McKinley County, New Mexico.

mation on current and recent weather and probable road conditions (Figure 2). WRRHAMS supplies immediate and up-to-date information to county road maintenance and emergency services personnel. This information allows timely response to damaged lifelines and appropriate routing for emergency services.

In addition to weather-related hazards, notable hazards common to many areas include variations in road

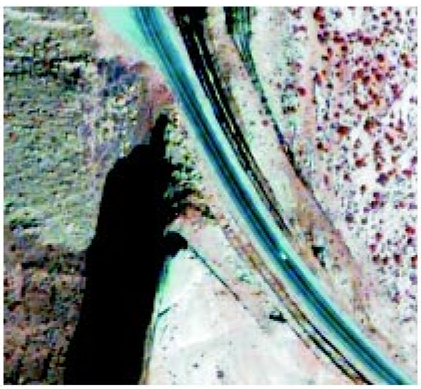

Figure 3. Pan-sharpened satellite image from DigitalGlobe used for identifying edge of road.

width due to placement of drainage structures (culverts) and cattle guards, high road curvature, rock-fall and slide hazards in areas of steep slope, and intersections where vehicles may meet. Each of these variables is a risk factor in analyzing transportation hazards.

A cooperative program with the Hopi Tribe in Arizona, assessed unimproved rural roads using remotely sensed imagery to identify and analyze hazards on Reservation roads.

Low-cost methods were produced to identify and analyze hazards on unimproved Hopi roads. These methods use a raster-based GIS system to facilitate direct integration of satellite imagery with other forms of gridded data, such as digital elevation models (Figure 3). By assigning risk factor weights to different GIS layers, users can create composite maps that reveal hazardous

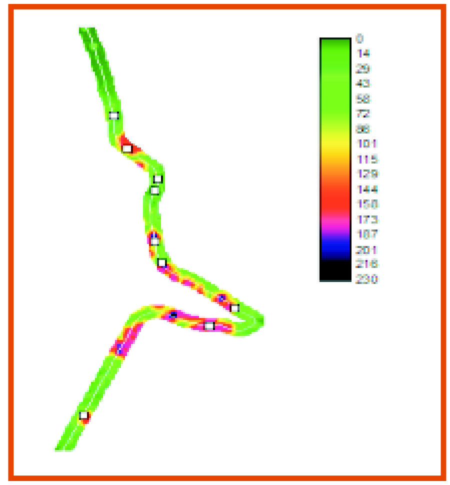

Figure 4. Risk maps of road hazards developed from remotely sensed data using multi-criteria evaluation.

road sections (Figure 4). These methods are fully applicable to a wide variety of geographic regions throughout the world, improving road safety and trafficability while reducing management costs.

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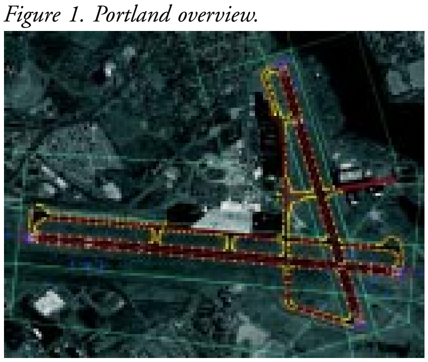
Airport infrastructure planning and development support

Spatial information and technologies can be used to help increase the capacity of our national airspace system, while maintaining the high safety requirements and increased security that air transportation demands. A NCRST-sponsored Technology Application Partner accomplished this by providing

Figure 1. Portland overview.



valuable spatial information, such as remotely sensed data, to airport, Department of Transportation and Federal Aviation Administration users using modern, web-based Geographic Information Systems (GIS) technology. GIS has been applied in this manner to airport construction planning and coordination, airspace management, environmental streamlining, utilities management, airfield safety, obstruction analysis and many other application areas.

While there are a variety of areas in which these technologies can be applied, this project has verified that differing airports have, for the most part, very similar needs. Despite their similarities, however, most are

Figure 2. Portland airspace.

approaching the task of implementing GIS technology independently. Many are developing their own data standards, not utilizing national data sets or duplicating surveying efforts. While inefficient, adopters of these technologies have been left with few alternatives due to the lack of coordinated and publicized federal initiatives focused on airport requirements for spatial data and technology.

The problem was addressed by applying remotely sensed data, leveraging nationally accepted spatial data standards and packaging all of this into a widely accessible web-based GIS tailored to meet airport needs. The data include high-resolution satellite imagery and LIDAR data combined with the traditional CAD data produced by airports. The data was organized using National CADD/GIS Technology Center Spatial Data Standards. ESRI's ArcIMS was used to deploy the data over the Internet within a graphical user interface. The result, shown in Figure 1, has been deployed to the Portland International Jetport (Maine) and the Ted Stevens Anchorage International Airport (Alaska). Airport, FAA and DOT are among the users.

In addition to the web application, this product includes standards, methods and tools, to allow other airports to take advantage of the technologies. As more airports take advantage of this national effort, the result will not only be cost savings, but a much broader and more consistent use of data and technology. A more important benefit is that data related to airports will become more of a national asset that airport management, state officials and federal agencies can access, use and exchange as required. In this manner, the objectives and principles of the eGovernment initiative can be realized more fully within the aviation sector.

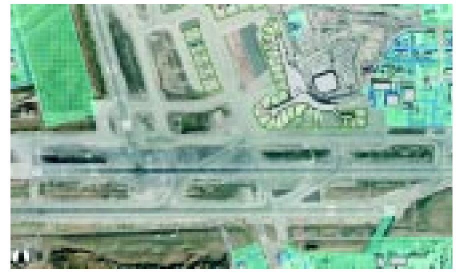


Figure 3. Anchorage airport

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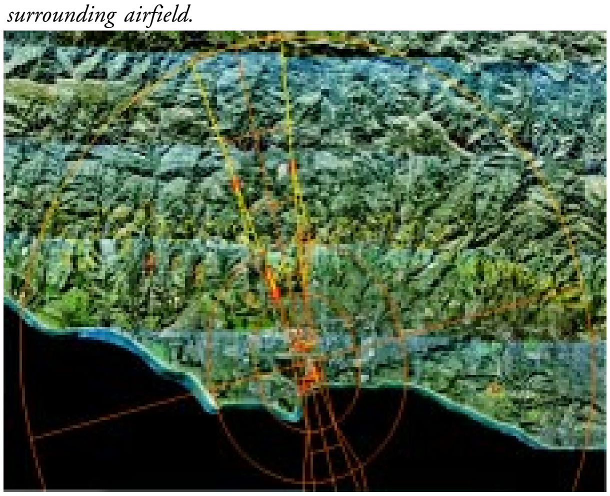
Identifying glide path obstructions at the Santa Barbara Municipal Airport

Airports require timely surveys of the approaches to airfield runways and the surrounding area to identify new and potential obstructions that can compromise aircraft safety. Protecting and managing airfield facilities and enhancing airspace safety requires complex 3-D information about the relationships of features in the airport environment. LIDAR and digital photogrammetry are complementary technologies that provide spatially enhanced data and analysis capabilities to meet this challenge.

NCRST, in collaboration with commercial partners, initiated the Airfield Initiative Remote Sensing Technology Evaluation Project (AIRSTEP), a case study of the Santa Barbara Municipal Airport in California, to assess whether LIDAR and aerial photogrammetry could meet management, security, and planning needs of the airport.

A high-resolution digital terrain model was produced from GPS-controlled LIDAR data and aerial photography (Figure 1). The analysis identified obstructions that potentially endanger approaching aircraft. These products provide the airport and pilots with up-to-date information to ensure aircraft and public safety and to meet Federal safety regulations. Without aerial data support for this application, expensive ground surveys of very large areas are required. Scheduling these surveys requires several years, which contributes to long delays in their execution.

Figure 1. Obstruction identification surface derived from LIDAR data and aerial photography. These data were used to locate and identify hazardous obstructions along runway approaches and the surrounding airfield.



Imagery also provides the basis for high-precision mapping of airport facilities and their surrounding environment, which are two critical components for managing today's airports.

Photogrammetric analysis allows planimetric and volumetric extraction of buildings and other structures in, and surrounding, the airfield. One-meter mapping and terrain modeling are facilitated by both LIDAR data and aerial photography.

Products were provided to managers at the Santa Barbara Municipal Airport for in-house mapping and GIS production. Remote sensing data in a GIS format provide accessible, yet critical, up-to-date information for facilities planning and security decisions.

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New tools for hazards and disaster preparedness AND LIFELINES SECURITY

Remote sensing and geospatial information technology offers new solutions for managing transportation safety, hazards, and disasters. The management challenges include a wide array of technical and operational issues including predicting, preventing, and mitigating disruptions to the nation's transportation infrastructure, and maintaining the flow of goods and services. The NCRST results have produced practical and cost-effective disaster management solutions for use by state DOTs and local transportation authorities, public safety offices, and emergency preparedness agencies.

Assessing the accessibility and trafficability of rural road networks in advance permits public awareness on service disruptions that relate to critical transportation requirements such as commercial deliveries, mail, and alternative emergency services. Enhanced 911 (E-911) is an example of a new geospatial analysis application using high-resolution satellite imagery. Rapidly expanding communities and residential subdivisions demand that first-responders be provided with frequent updates on surface transportation bottlenecks, locations of maintenance and repair crews, and alternative routing scenarios. The impacts of road closures, traffic accidents, toxic spills, and other disruptions to traffic flow require ever-more sophisticated techniques for incident management. The complexity of required services, combined with overlapping jurisdictions and the multiplicity of responding agencies, have led to greater demand for data and information sharing, especially in context of preventing or mitigating terrorist attacks.

Every state is faced with both common and unique mandates and information requirements for seeking effective solutions to transportation safety, hazards, disasters, and security. NCRST has focused foremost on these requirements and also explored specialized remote sensing applications such as: (1) identifying avalanche-prone road and railroad segments; (2) finding areas of high risk for slides, slumps, and subsidence; (3) identifying and mapping aircraft glide-slope obstructions for commercial aviation; (4) locating risk-sites for pipeline ruptures; (5) assessing sensor requirements for early warning of dense ground-fog episodes or for detecting trace amounts of biochemical agents at international border crossings; and (6) exploring the use of uninhabited aerial vehicles (UAVs) for remote surveillance as a means for intercepting possible terrorist materiel on ships, planes, trains, and containerized cargoes. Several of these exploratory efforts have lead to useable solutions for transportation applications.

Evaluating infrastructure adequacy in a small neighborhood

In the Oakland Hills, California fires of 1991, 25 people perished in their cars, stuck in traffic while evacuating their neighborhood. A number of factors contributed to this death toll: the configuration of streets that made access and egress difficult; lack of preparedness to deal with the special circumstances of the neighborhood; and the tendency of residents to take both or all household vehicles while evacuating, leading to unprecedented congestion.

In Santa Barbara and Thousand Oaks, California, remote sensing combined with GIS and microsimulation modeling is helping transportation and emergency planners deal with these situations before another tragic incident similar to Oakland Hills develops. Hyperspectral imagery

The Oakland Hills, CA fires of 1991. Credit: Paul Kienitz distinguishes between wood and composite roof shingles, identifying areas most prone to fire propagation in urban areas. Detailed neighborhood maps with information on street width and capacity, combined with household population counts, are fed into the Paramics® traffic microsimulation model. Evacuation is modeled at the level of the individual vehicle, and clearance time estimated. Simultaneously, the movement of emergency response vehicles *into* the neighborhood is modeled, so as to identify bottlenecks and sections of the network where the response time is in excess of acceptable standards.

The NCRST team is working with state and county officials on a number of remedial measures, e.g., to widen critical arteries; to identify private gated roads that may be opened to carry traffic in an emergency; to alert public safety personnel for traffic control; and to educate residents on the importance of minimizing the number of vehicles used for evacuation.

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Planning community evacuations for large populations

Regional evacuation is a major strategy in response to disasters, such as hurricanes, forest fires, nuclear reactor failure, release of toxic gases, or acts of terrorism. To support evacuation analysis and planning, information related to road networks, traffic control characteristics, and dynamic population distributions is required to delineate emergency zones, estimate at-risk populations, determine evacuation routes, and identify vulnerability and capacity constraints of the road infrastructure. Remote sensing and geographic information technologies can improve the efficiency and effectiveness of data acquisition. They assist in preparing road networks, estimating population distributions during daytime and nighttime, and identifying critical facility locations such as schools, hospitals, and shopping centers that need special attention during an emergency.

Information about road network geometry, connectivity, and roadway characteristics is the foundation for evacuation routing, simulation, and analysis. High-resolution imagery allows much of this information to be extracted in a GIS environment.

Traffic simulations for evacuation analysis and planning near the Sequoyah Nuclear Power Plant in Hamilton County, Tennessee, incorporated information derived from remote sensing and GIS sources.

Six-inch, high-resolution orthophotos were used to establish road network geometry and connectivity (Figure 1).

Field crews collected data on traffic control characteristics, e.g., stop signs, traffic speed, and placement of traffic control devices. Nighttime and daytime population distributions were used to estimate origins and destinations of vehicles in a hypothetical emergency.

The simulation focused on traffic conditions at night, which is the basis for comparing traffic conditions during the day. Nighttime population estimates are derived from the Bureau of the Census data because most people are home during the night. The goal is to understand differences between daytime and nighttime population distributions and their impact on evacuation analysis and planning, such as different vulnerabilities during daytime and nighttime. This information aids in planning mitigation strategies for vulnerabilities.

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Figure 1. Road network extracted from six-inch, high-resolution imagery.

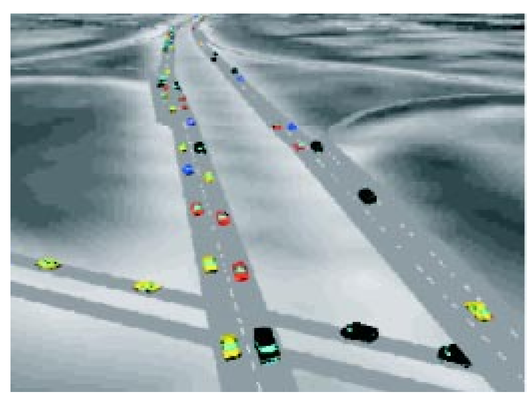

Figure 2. A simulated traffic scenario for an intersection near the Sequoyah Nuclear Power Plant site.

Integrating remote sensing technology for planning during emergencies

Residential development in fire-prone wildlands is occurring at an unprecedented rate. The relatively large evacuations that occurred in Colorado, New Mexico, and Oregon in the summer of 2002 are an indication of the growing population in these areas. Many threatened areas do not have an evacuation plan, and community-based emergency planning is an emerging need.

Emigration Oaks is a planned urban development in a canyon east of Salt Lake City, Utah that is chiefly vegetated with Gambel Oak. Gambel Oak has a fire recurrence interval of between 35 and 100 years and can support flames from 50 to 100 ft high moving at 8 to 10 mph in high winds. Most of the development in this community occurred in the last ten years, and there are some 250 homes along a six-mile network of narrow, winding roads with one exit. An evacuation could involve as many as five or six hundred vehicles depending on the time and day.

Satellite imagery and data from the developer were merged to identify the road network and location of homes in the subdivision. This information was used with off-the-shelf microscopic traffic simulation software to design and test neighborhood evacuation plans in the urban-wildland interface. The method allows an analyst to map the sub-neighborhood variation in household evacuation travel-times under various scenarios. This allows an analyst to assess which families could be trapped in a transportation bottleneck during a fire. It also identifies the location of the bottleneck.

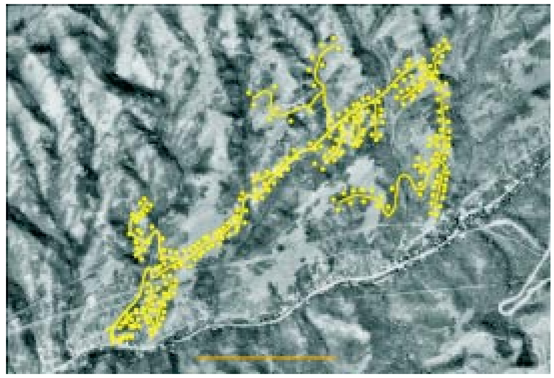

Figure 1. Location of each building lot in the Emigration Oaks subdivision.

Figure 2 depicts the mean household evacuation times for a relatively urgent evacuation of Emigration Oaks where an average of 2.5 vehicles departed each household and the mean departure time following notification of the entire neighborhood was 10 minutes. Figure 3 shows the effect of providing a second exit for this community. Note that, given the new road, the evacuation travel time for households in the back of the canyon decreased the most, but all household times became more consistent.

This application supported the county's decision to build the second road. It demonstrated to the residents and planners that the new road significantly alleviates traffic problems during an evacuation. The second route was recently completed.

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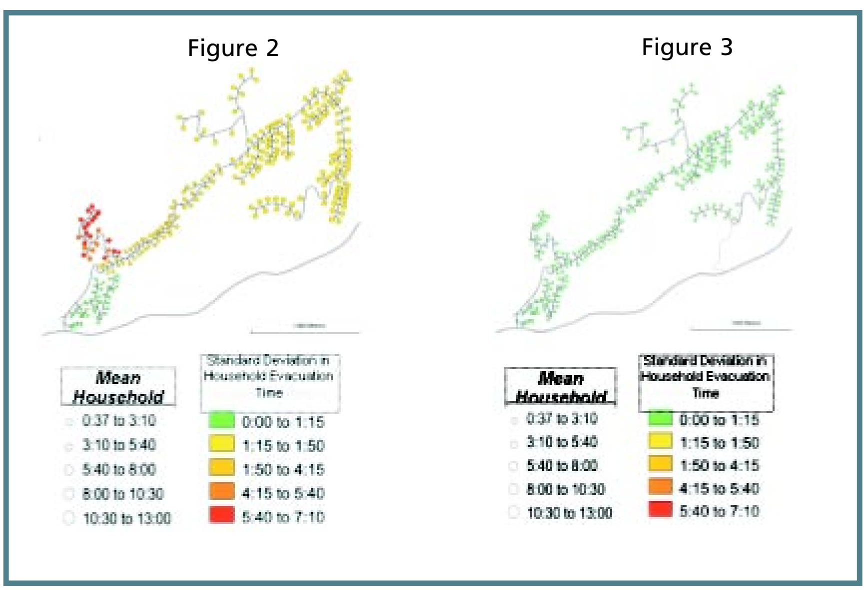

Figure 2. Evacuation scenario with only one exit route.
Figure 3. Evacuation scenario with two exit routes.

Detecting disaster-damaged bridges for emergency response in Southern California

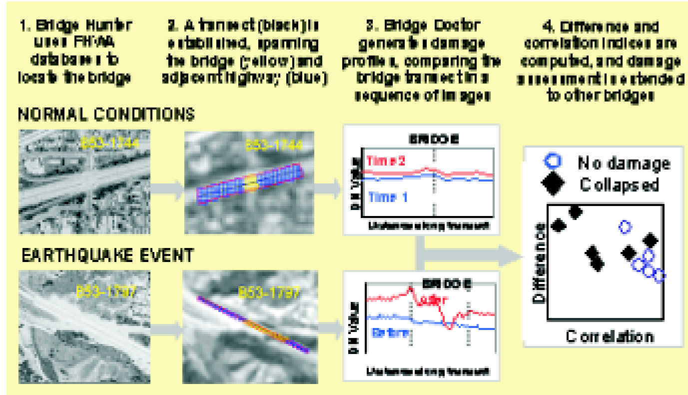

Figure 1. Change detection process for Bridge Doctor.

Figure 2. Bridge Hunter and Bridge Doctor "end-to-end" solution.

In extreme events, such as terrorist attacks and natural disasters, the performance of critical transportation lifelines is a major concern. With 600,000 bridges and 4 million miles of road at risk in the United States, effective response and recovery efforts demand near-real-time damage assessment.

Airborne and satellite sensors present a high-resolution, synoptic overview of the highway system, for monitoring structural integrity, and assessing damage following an event. NCRST and Caltrans teamed to demonstrate the application of *Bridge Hunter* and *Bridge Doctor* algorithms for detecting damage to highway bridges using data from the 1994 Northridge earthquake.

Phase 1 of the damage detection process employs *Bridge Hunter* to locate and compile a catalogue of remotely sensed imagery, together with attribute information from databases such as the National Bridge Inventory (Figure 1). During Phase 2, *Bridge Doctor* diagnoses the 'health' of bridges, determining whether the structure sustained catastrophic damage. Bridge damage is quantified by the magnitude of change between a sequence of images acquired 'before' (Time 1) and 'after' (Time 2) the event. In general, the hypothesis is that for collapsed bridges, where part of the deck fell or was displaced, substantial changes will be evident on the imagery. In the case of 'no-damage', change should be minimal. Resulting damage profiles (Figure 1) clearly distinguish between these extremes.

Bridge Hunter and *Bridge Doctor* have vital roles to play in emergency response, following a terrorist attack or natural disaster. An 'end-to-end' application is illustrated in Figure 2. Satellite and airborne remote sensing technologies transmit images to earth, enabling synoptic monitoring of critical transportation assets. A catastrophic event occurs. 'After' images are acquired across the U.S. and transmitted to a centralized geospatial information system. Bridge signatures are compared with the 'Before' case. Damage is detected on several highway bridges in Los Angeles. Their locality is immediately ingested into the FHWA/MCEER REDARS network-modeling program to generate critical intelligence for emergency managers.

REDARS computes least cost journeys. The scenario in Figure 3 shows the effect of a bridge collapse (yellow symbols) on traffic congestion (black line thickness) in Los Angeles. The former (yellow line) least cost route now follows an adjusted course (red line) between designated start (S) and end (E) points.

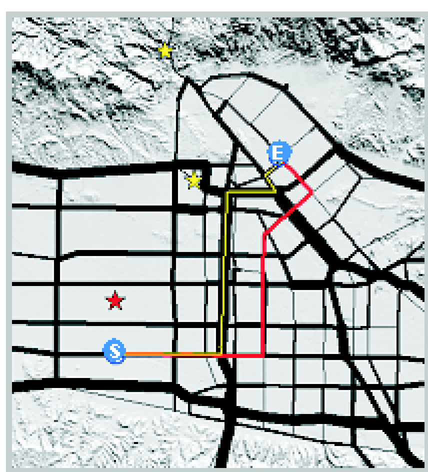

Figure 3. REDARS adjusted least cost route (red line) in response to bridge collapse. The original route is shown in yellow.

With this information at hand, emergency services are directed through the chaos and evacuation routes are established. The program tells emergency managers where to reroute traffic to minimize congestion and contributes to the initial loss estimation preceding a presidential declaration.

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Tools for regional monitoring of highway bridges

Bridges are a critical element of the highway infrastructure, with more than 600,000 structures in the jurisdiction of state DOTs. Effective management of bridge assets is a considerable challenge, which is at present structured around nation-wide databases, such as the National Bridge Inventory (NBI). Although comprehensive in terms of bridge attribute information, these databases are compiled in a tabular format.

Remote sensing technologies enhance these databases by providing a visual perspective of highway bridges. Information derived from imagery adds value to existing attribute-based strategic and tactical bridge management practices.

Recognizing the potential value of visual records and imagery information, NCRST worked with Caltrans to develop a custom software program that augments existing national databases with a detailed image catalogue. *Bridge Hunter* is an automated algorithm, which 'tracks down' highway bridges in remotely sensed imagery, generating high-resolution scenes and accompanying attribute information.

Bridge Hunter draws on National Highway Planning Network (NHPN) and Highway Performance Monitoring System (HPMS) databases to refine the latitude and longitude of NBI bridges. Dynamic segmentation processing produces revised coordinates, enabling the accurate location of bridges on airborne and satellite imagery.

Figure 1. Earthquake damage to a bridge on the I-5 in Gavin Canyon.

In tests supported by Caltrans, *Bridge Hunter* successfully tracked the sample of 950 Los Angeles bridges (Figure 2). Accompanying output from *Bridge Hunter* is depicted for bridge B53-1033 on the I-10. In this example, the visualization catalogue includes optical aerial photography and SPOT imagery, which reveal structural characteristics that simplifies the interpretation of ambiguous attribute definition; multispectral Landsat imagery that highlights surrounding land use and vegetative cover; and Intermap SAR data that records the proximity to highly reflective buildings and metallic objects, such as signs.

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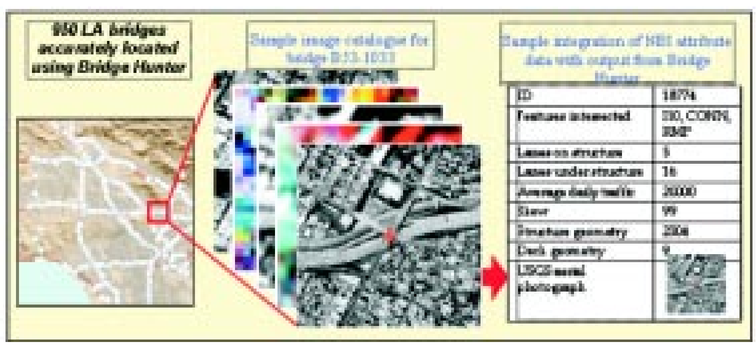

Figure 2. Sample of Los Angeles highway bridges tracked using Bridge Hunter and resulting output – image catalogue and associated attribute data.

Value of Visualization and Image Information for Bridge Management

Preparedness	Baseline remote sensing images record the status of highway bridges under normal conditions, prior to a natural disaster or terrorist attack.
Emergency response	Following a natural disaster or terrorist attack, the Bridge Doctor algorithm compares baseline images with remote sensing data acquired immediately after the event to establish the location and magnitude of bridge damage.
Vulnerability assessment	Visual inspection of multi-sensor imagery reveals the proximity of bridges to leaking pipelines, industrial plants, and other transportation links.
Hazard monitoring	A temporal sequence of remote sensing images records environmental changes that may affect the highway system.
Routine monitoring	Imagery supports periodic inventory updates as new construction proceeds, and for day-to-day management, records deterioration of the surface deck and maintenance undertaken

Transportation hazards consequence tool

The vitality of today's communities is tied inextricably to the performance of its transportation lifelines. Given this dependence, network vulnerability can debilitate urban systems in the face of unplanned, hazard-induced disruptions .

There is little question that traffic congestion is a severe and growing problem in many urban areas in the United States. Traffic congestion has substantial negative effects on urban residents and businesses. These impacts include loss of productivity and restricted accessibility to the urban environment. Many urban transportation networks are operating at or near capacity, rendering them especially vulnerable to congestion resulting from unplanned disruptions such as accidents or hazard induced infrastructure failures. This congestion propagates throughout the network over time as congested conditions spread to neighboring links. Being unexpected, such incidents place burdens on the network unanticipated by planners and policymakers during transportation planning and construction. Conducting a network vulnerability analysis could mitigate problems stemming from network congestion.

The Transportation Hazards Consequence Tool (THC) offers a solution for public policymakers and planners in building transportation systems that are robust in the face of unplanned disruptions. It assesses the impact of transportation network loss on flows within the network, and it examines changes in network flow and congestion, changes in travel times, and changes in shortest path routes.

THC provides the computational environment for assessing network vulnerabilities, allowing for numerous "what-if?" scenarios. Network disturbance and reduced service scenarios are simulated and analyzed to identify network vulnerabilities. These disturbances include removal of a network link to simulate the failure or destruction of a road or bridge. It also can reduce the capacities of links in the network to simulate poor weather or emergency conditions.

The strategy is to integrate data and imagery in a GIS with a dynamic flow model. The dynamic flow model captures system-wide impacts on congestion and its propagation over space and time.

The Transportation Hazards Consequence Tool was tested using data for the northeastern quadrant of Salt Lake City, Utah. Three query options are offered:

The **Individual Link Query** tool provides a view of the effects of the network disruption on a selected link. It provides options for traffic flow, travel speed, travel time, and congestion. Each of these can be displayed as either change in volume or change in percentage. Either direction of travel for a link can also be specified.

The **Network Query** tool shows the change in traffic flow, travel speed, travel time, or congestion in a specified time slice. The user specifies a change criterion. This is the percentage of change from the base scenario the link must meet to be shown as having either increased capacity or reduced capacity.

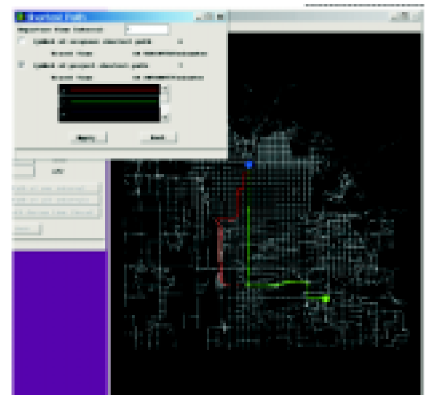

Figure 1. The shortest path between two network nodes during a specified time interval. The base scenario shortest path is shown in red, while the disrupted network scenario is shown in green.

The **Dynamic Route Query** tool identifies the shortest path between two selected points for both the base scenario as well as for the reduced capacity scenario. Three types of shortest path queries can be made: shortest path during one interval, shortest path during all intervals, and shortest path during a user specified time thread.

In the shortest path during one interval query, a single time slice, is specified and the shortest paths for both the base scenario and the reduced capacity scenario are found and displayed with different colors chosen by the user.

In the shortest path during the "all intervals" query, the travel time for both shortest paths are listed for trips originating in each time slice.

The shortest path during a time thread query allows the user to input a beginning time slice and an ending time slice for a trip. The shortest paths, again for the base and the disrupted network scenarios, are calculated.

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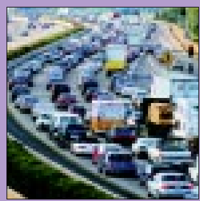
Expanding horizons
for traffic and freight flow
MONITORING AND MANAGEMENT



Improving the efficiency, safety and security of transportation systems at competitive cost will rely heavily on advancing technologies for monitoring and managing passenger and freight flows over the nation's surface transportation systems, through its ports, and across its borders. These technologies will be particularly important for expanding the capacity of existing surface transportation systems, since physical expansion of the facilities is practically impossible in many cases. As input to such capacity expansion, transportation engineers, planners and managers seek more precision, improved timeliness, and lower cost in measuring vehicular and transportation flow over the nation's multimodal transportation infrastructure specifically in non-urban, regional, and rural transportation systems. They also seek to obtain such measurements with less disruption to traffic streams and with increased safety to the personnel involved.

Advanced traffic and transportation management tools using high quality remote sensing imagery and spatial information systems can provide improved and intelligent transportation services. Applying remote sensing tools for traffic flow measurements can safely determine the flow status of regional and statewide surface transportation networks in a timely manner. The NCRST team has advanced the concept of integrating remote sensing technology with Intelligent Transportation Systems (ITS) to expand existing ITS user services at the region-wide level, especially in non-urban and rural areas and border crossings. The advent of NCRST remote sensing technology application developments has the potential to significantly contribute to achieving smarter and more efficient management of transportation flow for 21st Century Transportation.

NCRST projects have successfully tested the potential of several new applications of remote sensing technology and tools for estimating flow characteristics at both regional (average daily traffic, vehicle miles traveled, OD volumes, path flow) and local (vehicle speeds, link travel times, densities, turning ratios, intersection level-of-service) scales. Several project results provided the blueprints for tailoring appropriate information processing techniques to the specific operating conditions in which the remote sensing technologies (high-resolution satellite imagery, LIDAR, video) were applied to analyze transportation flow. Groundbreaking advances were also made in the planning, scheduling and acquisition of images from moving, air-based platforms for efficient collection of traffic status in transportation networks. Pioneering project achievements include application trials of Unmanned Aerial Vehicle (UAV) technologies for monitoring and managing traffic flow in highways, transit and multimodal transportation systems.

Image-based backdrop improves real-time bus information system

The Ohio State University Campus Area Bus System operates approximately 30 buses over roughly a dozen scheduled service routes in and around the campus area. For several years, a GPS-based location system has been used for real-time passenger information and off-line performance monitoring. Among other things, bus locations are displayed in near real time at a web site on a simple map background, as illustrated in the captured screen in Figure 1. At home or in the office, riders can check on the location of the buses on the system to time his or her arrival at the bus stop to coincide with the arrival of a bus.

NCRST investigators have enhanced this system by replacing the simple map with an image backdrop of the area. This simple idea has proven to be a pleasing option for users and

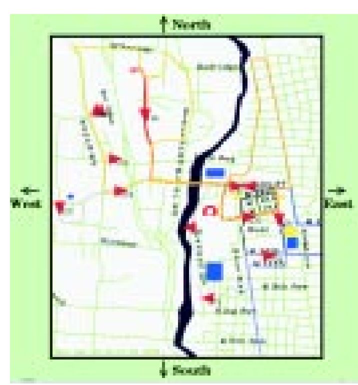


Figure 1. OSU campus bus locations on a map backdrop.

extremely well received by system administrators and operators. The increased “high tech” and more aesthetically pleasing appearance of the information, illustrated in the captured screen in Figure 2, provide a more pleasant experience to those visiting the site. People seem to relate to the image backdrop more quickly than to the map backdrop. If marketed well, such an appearance could generate a more positive image of the transit agency among users and non-users alike. A more positive image can translate into increased interest and greater community support for public transit options. A more visually realistic background can also provide assurances for parents and administrators concerned with daily transport of school children. System operators can also more easily monitor bus movements, record deviations from scheduled routes, and quickly identify problem areas and dispatch assistance.

Further straightforward extensions, such as: (1) updating bus positions every 10 sec rather than the current every 60 sec, and (2) allowing the user to click on the image of a building and having the name and/or address of the structure appear visually on the screen, or verbally, are possible. Other more complex uses, such as using cell phones to suggest changes in location for patrons to disembark based on changes of plans and/or speed of bus along the route could be facilitated. Results from viewing the system are available at http://blis.units.ohio-state.edu.

Figure 2. OSU campus bus locations on an image backdrop.

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Applications for traffic operations

Remote sensing offers traffic managers and analysts an additional set of sensors to monitor traffic conditions and to evaluate traffic operations at intersections and arterials. Data from remote sensors can be used in conjunction with existing ground sensors to enhance traffic monitoring and control.

In one salient example, NCRST investigators have been working on a project that uses existing ground sensors to monitor real-time traffic flows and to improve traffic signal timing. The computer software involved is called RHODES, which determines the green times at traffic signals to reflect real-time estimates of the vehicles waiting for the green light.

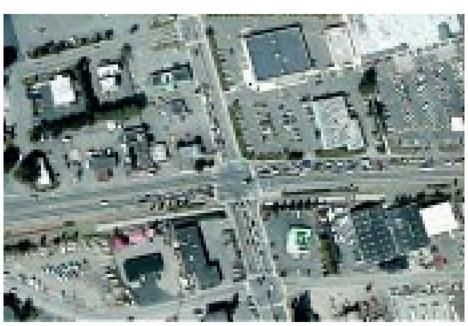

Figure 1. Airborne image from intersection in Seattle RHODES test.

In August 2002, the Washington Department of Transportation conducted a field test of RHODES. In that test, seven intersections along State Route 522 were equipped with the RHODES software and the performance of the system was evaluated. As part of the evaluation, an NCRST team worked with investigators from the University of Washington to collect digital video from a helicopter over all seven intersections. The imagery collected from the helicopter is presently being used in the following ways:

The images provide “ground truth” by which vehicle queues and delays at each intersection can be determined. An airborne platform can cover the entire intersection using one set of images, compared with having several manual data collectors on the ground. The airborne platform can thus reduce much of the significant labor costs associated with the travel time probes and ground observers conventionally used in evaluation of intersection operations.

The images lead to estimates of other traffic parameters that are used in RHODES. These parameters include: the rate at which cars cross the stop line, the number of trucks and buses, the relative use of different lanes at the intersection, and the fraction of vehicles turning in each direction.

While the analysis being done for this test is largely after the fact, the NCRST investigators are exploring ways in which data from both ground and airborne sensors can be integrated to provide information for more efficient traffic signal control in real time.

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Cheaper and more accurate highway traffic measures using satellite and airborne imagery

NCRST researchers have shown that the information in satellite imagery and air photos can decrease estimation errors in average annual daily traffic (AADT) and vehicle miles traveled (VMT). AADT and VMT are two of the most important traffic measures produced by state department of transportation (DOTs) and other transportation agencies around the world. Agencies determine AADT as the indicator of vehicle flow over a specific highway segment on a typical day of the year and VMT to summarize travel over the entire highway system during a period. AADT is a critical input in many design, operations, and safety-related decisions, while VMT is used to indicate mobility patterns, travel trends and as the basis of federal policy decisions on allocating highway resources.

The NCRST team has further shown that combining ground-based data with the information in the imagery can drastically reduce present data collection expenses. Present practice requires ground crews to sample traffic across their state on an aggressive and costly schedule. Figure 1 depicts a typical set of Ohio highway segments sampled for traffic volumes in one year under the existing system that uses ground-based data collection methods. To collect the samples, the crews place detectors on busy road segments. This disrupts traffic and endangers the crews during detector placement and removal. Using satellites and air-based platforms, crews can cover large areas and access remote highways from safe and non-disruptive off-the-road locations. Figure 2 depicts the set of Ohio highways that could be sampled in one year when adding images that could be obtained from the 1 m panchromatic Ikonos sensor to the ground-based samples of Figure 1.

Figure 1. Typical set of Ohio highway segments sampled in one year with ground-based data collection.

Figure 2. Typical set of Ohio highway segments sampled in one year when combining satellite- and ground-based data collection.

The imagery collects “snapshots” of traffic over large areas at an instant of time, whereas traditional data collection counts vehicles at a point on the highway over much longer time intervals. The researchers developed procedures to convert image-based data to information that could be combined with ground-based traffic data. They applied their procedures to satellite images and air photos of over 20 urban and rural interstate segments in Ohio and compared the resulting estimates to those produced from ground-based data. The differences were small. Feeding these results into computer simulations developed for AADT and VMT estimation over large geographic regions, the researchers discovered that combining even a fraction of the data collected from a single satellite with data collected on the ground would allow a reduction of more than 50% in ground-based sampling efforts while substantially increasing the accuracy in the AADT and VMT.

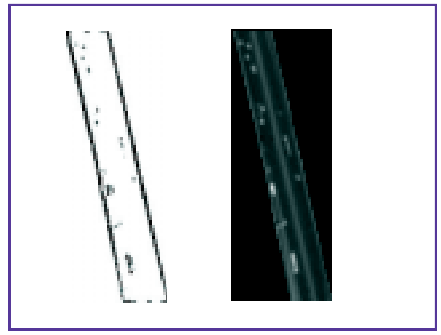

Figure 3. Highway segment with vehicles from Ikonos 1-m panchromatic image (left) and resulting binary image (right) from consortium-developed image processing software.

Widespread application of these procedures would require automated procedures to efficiently produce traffic information from the satellite and airborne imagery. The team therefore developed methods to address the unique characteristics of satellite imagery and demonstrated their promise on Ikonos satellite images and air photos (*e.g.*, Figure 3).

To facilitate the realization of the benefits, the researchers are verifying their results on multiple types of highway facilities, refining their image processing techniques, determining costs of image collection and processing that could be compensated by the cost savings in ground data collection, and promoting the studies among state DOTs.

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Determining highway level of service using airborne imagery

Engineers regularly measure traffic variables to assess the quality of service provided to the traveling public. A variety of measures is used to quantify the "level of service" of roadways and traffic, including speeds over stretches of the highway, delays, the flow of vehicles per unit time, and density of vehicles per unit length of roadway. Current traffic sensor technology, which is based on collecting data at a single point on the roadway, does not allow for direct measurement of these variables. Traffic flow can be measured with the current technology; however, engineers must rely on inexact methods to convert traffic flow measures into the more useful measures of densities, speeds, and delays.

Figure 1. Freeway image from I-10 in Tucson, Arizona.

In contrast to the traditional approach, remotely sensed data from airborne and satellite imagery has the advantage of capturing traffic patterns on a wider spatial scale and *directly* determining highway speeds, densities, and delays. Vehicles can be observed as they really are distributed on a stretch of roadway, giving density measures directly. Vehicle speeds can be estimated by tracking cars as they travel along the road. Intersection delays can be estimated directly by observing how long a vehicle spends at the intersection. Such direct measurement improves the accuracy of the data and the resulting performance measures that are fundamental to planning, monitoring, and operating the highway system.

NCRST investigators have developed methods that exploit the power of airborne imagery and convert the imagery into direct measures of density, speed and intersection delay. Through a series of "cookbooks," they have also provided step-by-step guidance on determining the commonly used Level of Service measures used by engineers and planners across the world.

Compared with traditional field data collection methods, the airborne imagery requires a different approach to data collection and analysis. Freeway traffic density, as one example, can be observed directly from imagery taken over the freeway. The investigators are developing means to determine density from the imagery automatically, with minimal human intervention. They are also developing means of sampling so as to obtain good statistically representative estimates of density at low cost.

In the second example, airborne imagery allows one to track a significant number of vehicles simultaneously. This allows direct measurement of speeds over longer distances and gives more statistically valid estimates of these speeds. Automated data reduction is now feasible with current technology and algorithms developed by the NCRST investigators.

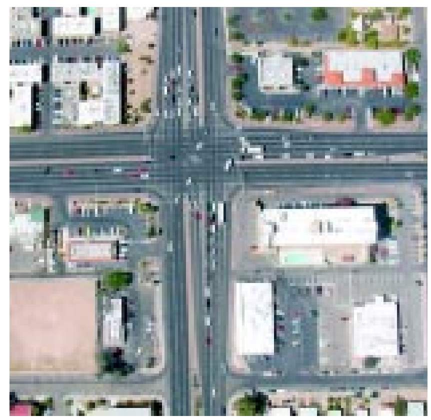

Figure 2. Image of intersection monitoring from Tucson, Arizona.

Finally, measures of delay at intersections typically require significant observation on the ground to determine how long vehicles must wait. Having a remote view allows the vehicle movements through the intersection to be observed directly, giving more accurate estimates of delay. NCRST investigators are presently developing ways to automate the procedures involved with producing these estimates.

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Improved freight flow management

Freight flows in the transportation system occur over large areas, primarily under the purview of private companies with little or no mandatory reporting of their activities. Consequently, remote sensing technology (RST) offers a promising opportunity to acquire large area and timely data about freight flows, thus contributing to improved private and public management of these flows.

Truck stop and rest area monitoring: Long-haul truck drivers park at designated truck stops and rest areas for extended periods of time, both for personal rest and to comply with regulations. Increased truck traffic has made the existing capacity insufficient to handle the demand for truck parking at many locations. Truck drivers respond to this shortage by parking on shoulders of entrance and exit ramps. At times the excess demand overflows to highway mainlines, disrupting traffic and posing safety problems. Aircraft can quickly survey an extensive geographic region to obtain relatively concurrent data on which truck stops and rest areas are operating under- and over-capacity. Trucks are also readily visible in high-resolution satellite imagery (Figure 1). As with most potential applications of remote sensing to transport flow problems, the greatest benefit would likely result from integrating both ground- and air-based information. The issues involved with implementing air-based surveillance to improve data collection would revolve about having a good database on parking capacities at the various facilities, and designing cost-effective sampling plans that respect physical constraints on air-based tours and satellite orbits and complement the ground-based data. Such a hybrid system could also serve as the basis of a real-time information system that would inform truckers of parking availability at upcoming rest areas (Figure 2).

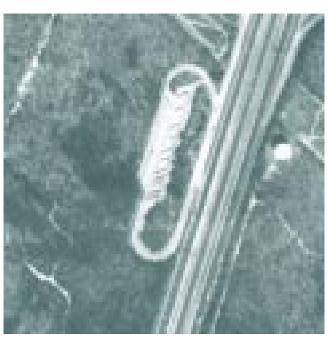

Figure 1. I-95 Dumfries, Virginia.

Figure 2. Potential real-time system combining RS and ITS.

Container storage in intermodal yards: Similar to surveying truck stop and rest area usage, imagery from air- or space-based platforms could be used to determine planning-level container storage at intermodal freight yards. For operations, on-site ground-based assessments would likely be more efficient, but to cover many facilities at a macroscopic level, the maneuverability and spatial coverage offered from aircraft and satellites might offer a cost-effective means of data collection. Container storage could be correlated with vehicular traffic (obtained either from the ground or from the air) to produce freight trip demand models. A study conducted by NCRST has demonstrated the potential to identify containers automatically from panchromatic imagery.

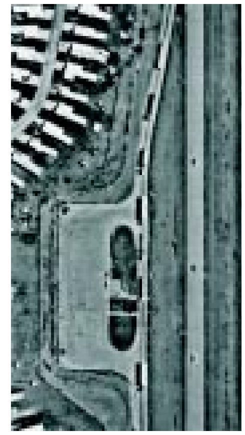

Figure 3. Ikonos 1-m image of weigh station in Findley, Ohio.

Vegetation in interior waterways: Rivers and other internal waterways are important conduits for freight traffic in countries across the world. Vegetation below and on the surface can inhibit transport of river-borne cargo. The locations of the vegetation can change fairly rapidly, and long sections of this transport system are remote and difficult to reach. Air- and space-borne platforms can readily access these sections and appropriate sensors can assess the extent of existing or anticipated problems.

NCRST and one of its Technology Applications Partners are testing the ability to map water hyacinth cover within a waterway using conventional classification, and investigating the ability of hyperspectral sensors to detect submerged plants. Satellite and air-based platforms are being used, and both seem applicable to this problem.

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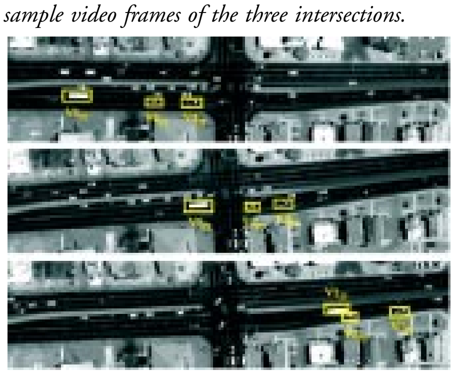
“Bird’s-eye” views of Transportation Networks for mitigating Urban Congestion

NCRST research efforts demonstrate that “bird-eye” view observations of vehicle movements through an intersection and their travel times along segments of the roadway can significantly enhance the real-time estimation of traffic volumes from their origins to their destinations. Such estimates, when accurate, are essential for effectively managing the flow of traffic on a network to address the ever-increasing problem of urban congestion.

Real-time traffic management has become an important function in addressing urban traffic congestion through traffic control and traveler guidance. Critical in achieving effective management is accurate knowledge of current and future estimates of traffic conditions. Therefore, management methods often employ network flow models that use data collected by a surveillance system to assess the current state of the network and predict its evolution over time. The network state is characterized by variables including origin-destination (OD) flows, link flows, link travel times, and segment densities. While all these variables are essential in describing traffic conditions, accurate OD flow estimates comprise one of the main inputs to the estimation of the other variables. NCRST research focuses on the role of various types of surveillance data in the real-time estimation of dynamic OD flows.

Figure 1. Network representation showing three sample video frames of the three intersections.



Traditionally, traffic surveillance is carried out using inductive loop detectors. These detectors, which are embedded in the roadways, provide data on vehicle presence and passage times across their point locations. Loop detectors can also be configured to provide velocities at these same locations. While providing an inexpensive means of monitoring traffic, such detectors do not provide any data on traffic conditions beyond the detection point. Recent advances in communication, computing, and electronics are resulting in the development of remote sensing based surveillance systems. Airborne video based sensors, an example of such technologies, involve the observation of the roadway network with video cameras mounted on airborne platforms. In conjunction with video image processing tools, such sensors can provide extended spatial coverage of the network, thus capturing vehicle trajectories, queue lengths, and link travel times in addition to the conventional point specific data available from loop detectors. An increase in the various types of data available has the potential to improve the accuracy of the network state estimates along with traffic predictions, and, consequently, result in more effective traffic management. The objective of NCRST research is to quantify the value of using intersection turning movement and link travel time measurements, which are available from airborne surveillance systems, in estimating OD flows in real-time.

A network consisting of three adjacent intersections was used to conduct an empirical analysis. Data were collected over three hours using video cameras located on a tall building emulating an ideal airborne platform. Figure 1 shows the network and the intersection views. The OD flow estimation results revealed two main conclusions regarding the subject network. First, using intersection turning movement data significantly improves the quality of the OD flow estimates. Second, using link travel time data in addition to turning movements, also improves the quality of OD flow estimates when the initial knowledge regarding the nature of the distribution of OD flows over space and time is poor. This is a common situation especially in the case of large urban networks.

While it is premature to generalize these conclusions due to the small size of the subject network and the absence of route choice, they clearly point to the potential value of using data reflecting wide spatial coverage, such as those provided by airborne-based sensors, in estimating current network conditions for real-time traffic management purposes. To generalize the above results, it is critical to consider a more complex network where route choice can be observed and utilize actual airborne platforms, such as remotely controlled aircraft and tethered balloons. Furthermore, the value of more accurate OD flow estimates on real-time traffic management along with the consequent reduction of urban congestion should also be quantified.

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Pioneering traffic data collection from UAVs for highway and multimodal transportation

The NCRST program is pioneering the use of unmanned aerial vehicles (UAVs) for transportation data collection. UAVs have already shown their worth in military operations. Vehicles can be programmed off-line and controlled in real time to navigate and collect surveillance data without putting pilots or crews in harm's way. In civilian transportation applications, collecting data without humans onboard can also result in important cost savings. Human crews contribute greatly to the cost of data collection, especially in cases of "on demand" operations, where crews are paid both while waiting for the possibility that a flight may be needed and while actually flying the aircraft.

Through funding as NCRST Technology Application Projects, two separate teams of investigators have developed vehicles that carry multiple payloads and demonstrated their capabilities on a number of flights. These vehicles weigh from 10 to 55 lbs and contain safety features that provide for safe landings in the event of trouble or loss of communications. Keeping weights under FAA-specified limits leads to fewer restrictions on allowable flight paths, reduces costs, and increases the possibility to fly more places at more times. Reducing costs permits an agency to use several aircraft, further increasing coverage potential.

The NCRST demonstration flights have illustrated the ability to transmit video in real time and to collect information on new land uses, traffic congestion, parking lot utilization, and condition of highway signs. The vehicles have covered urban areas, followed urban and rural transportation routes, tracked moving vehicles, and lingered over points of interest.

The demonstrated tracking capabilities will add security to transit operations and allow the UAVs to monitor suspicious vehicles. The maneuverability and low costs of the vehicles will be advantageous for collecting traffic, infrastructure, and land use data on a scheduled basis, while the ability to linger over specific locations will allow verification of traffic control parameters at signalized intersections and determination of turning movements for refined control settings and planning purposes. The quick take-off capabilities make UAVs ideal for rapid response to transportation incidents. Transmitting real-time video would be of great help in determining the correct response to an incident and assessing the appropriate information to provide motorists traveling in the vicinity.

Two years ago, suggesting that UAVs might be used for traffic data collection elicited mostly skepticism. Airspace restrictions, liability, and other institutional concerns that often accompany suggestions of implementing new technologies in established organizations were given as reasons why UAVs would never get off the ground. These issues are still potential impediments to large-scale deployment, but the successful NCRST demonstrations and the need to find flexible and inexpensive means of transportation surveillance have made UAVs one of the most talked about concepts in traffic flow data collection. Demonstrations are continuing, and the focus of the discussion has changed to determining how to overcome non-technical barriers so that agencies and the public can reap the benefits of this new technology.

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Airborne Data Acquisition System (ADAS) for traffic surveillance

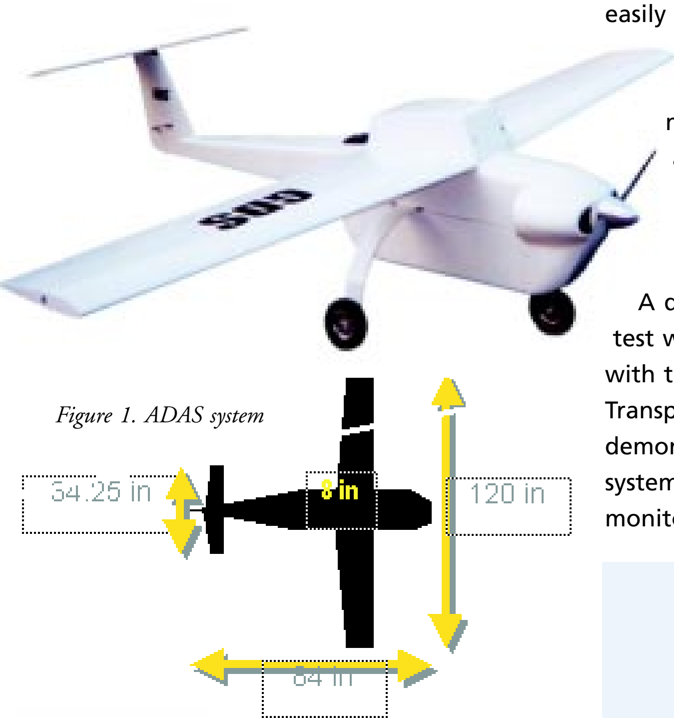

Figure 1. ADAS system

A NCRST Technology Application Partner is making use of an unmanned Airborne Data Acquisition System (ADAS) for traffic surveillance, monitoring, and management. This lightweight system can fly for more than two hours with a sensor payload of up to 20 lbs. The use of sensor-carrying unmanned aircraft can augment tools currently available. ADAS is not only inexpensive, but it requires only a two-man crew, and can easily provide various reconnaissance and surveillance information depending upon the mission need.

The ADAS is comprised of three primary components: an aircraft, a sensor pod, and a ground station. All ADAS components are easily shipped via FedEx overnight to anywhere in the country. One ground station can control up to four in-flight ADAS aircraft, each containing a single sensor pod. The three primary components of the ADAS system easily fit into an 8'x8'x4' quarter pallet. Once the system is unpacked, it takes less than 30 minutes to set up. The ADAS aircraft and ground system is specifically designed for easy use with minimal training.

A demonstration of capabilities test was performed in cooperation with the Virginia Department of Transportation. The goals were to demonstrate the feasibility of the system for traffic surveillance, monitoring and management. A section of I-64 in Tidewater, Virginia was the selected test bed. Two test flights were flown on 4 December 2001 and 18 April 2002. Better than 3-in. resolution was obtained. The imagery demonstrated the use of UAVs in real time traffic surveillance, monitoring of traffic incidents, monitoring of traffic signage, and monitoring the environmental conditions of roadside areas.

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Figure 2. Demonstration of 3-in. resolution attained with the images.

Figure 3. Images acquired on 4 December 2001.

Exploring LIDAR applications for traffic flow

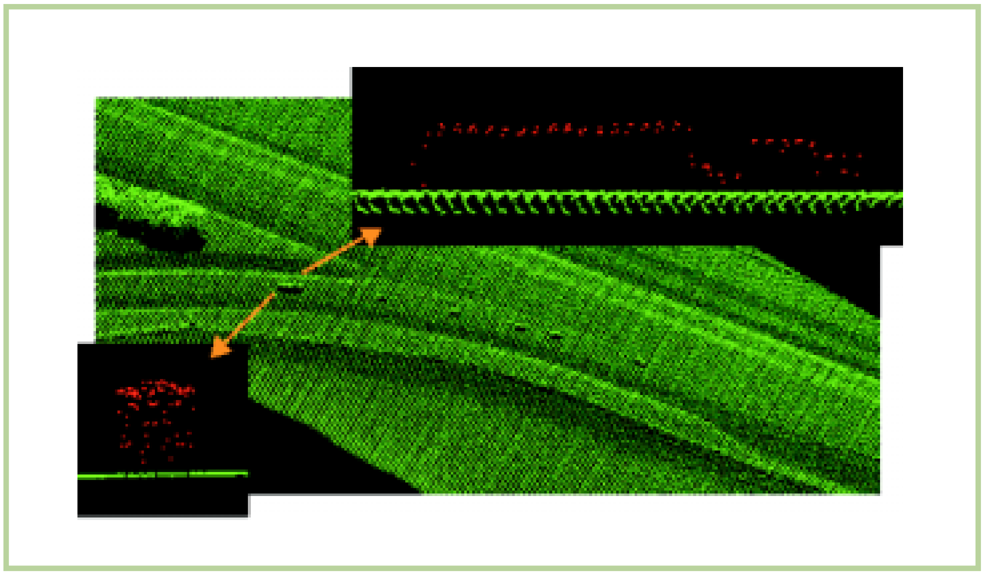

Figure 1. LIDAR image, courtesy of Optech, Inc.

LIDAR (or airborne laser scanning) systems have become a dominant player in high-precision spatial data acquisition in the late 1990's. Installed in aircraft and helicopters, these active sensor systems can deliver surface data at decimeter-level vertical accuracy in an almost totally automated way. In fact, this new technology has quickly established itself as the main source of surface information in commercial mapping. Despite the initial high price, these systems have made remarkable market penetration. Recent technical and methodological advancements have further improved the capabilities of this remote sensing technology.

Every indication is that transportation and other agencies will be deploying LIDAR systems over transportation corridors at an increasing rate in the future. Therefore, NCRST investigators investigated the potential of using LIDAR to detect and classify vehicles moving in traffic streams. The team has shown for the first time that civilian vehicles could be extracted from LIDAR data with good accuracy. In addition, they have also confirmed that vehicles can be reliably classified into categories, such as cars, trucks, and multi-purpose vehicles based on the pattern of the LIDAR returns. A Principal Component Analysis classifier, built on a 100-point training data set, delivered a better than 99% performance for a check data set. With appropriate LIDAR point density, the investigators have further determined that vehicle velocities can be estimated.

The NCRST team is involved in a project with the Ohio DOT designed to explore the LIDAR system to create accurate surface information of highways and areas around highways. Primarily for engineering purposes, the road surface must be determined at sub-decimeter level accuracy. Vehicles on the road represent obstructions to the LIDAR pulses sent to reflect off the pavement. Therefore, a substantial amount of processing must be devoted to "removing the vehicle signals." Rather than removing and discarding the signals, however, the investigators are turning them into traffic flow information. In this way, LIDAR surveys devoted to surface extraction will soon be able to provide a valuable byproduct with little additional effort.

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UAV applications for multimodal operations

A NCRST-sponsored Technology Application Partner (TAP) applied remote sensing and spatial information analysis technology to transportation infrastructure monitoring. An autonomous unmanned aerial vehicle (UAV) providing real-time video to a ground station on the UMASS Boston harbor campus was flown (Fig. 1). The UAV, called the "Bat," demonstrated several modes of operation, including an aerial survey mode that provided documentation of the new land uses in Boston's Columbia Point neighborhood and its recently redeveloped Harbor Point housing project. The Bat also demonstrated the aircraft's ability to provide continuous surveillance around a point, using the JFK library on Columbia Point as the focal point. The Bat demonstrated its *road following* capabilities to provide reconnaissance of the multimodal corridor from the Massachusetts Bay Transportation Authority's (MBTA) JFK/UMASS station south along the I-93/Red Line South/Old Colony commuter rail corridor. The UAV followed an MBTA Red Line train along the corridor producing real-time video imagery (Fig. 2). The Bat UAV monitored traffic conflicts along Morrissey Blvd, a major arterial roadway in the Dorchester neighborhood. The operation was not detectable by pedestrians or motorists in the area.

Figure 2. Bat UAV in flight.

The Bat UAV is flown autonomously using a computer-generated flight plan. The 10 lbs UAV has the latest safety features, including an automatic "*go home*" feature, should communications with the aircraft become interrupted, and an automatic engine shut-off and parachute deployment. The Bridgewater State College Police Department and the UMASS Boston Police Department provided public safety coordination for the flight during take- off and landing. The MBTA police, MBTA operations staff, and the Bristol County Sheriff's Special Operations staff cooperated in the planning and evaluation of the UAV remote sensing demonstration.

Figure 1. Bat UAV on launcher.

The UAV flight path followed a portion of a similar flight path of an RF-101 reconnaissance jet aircraft, as a part of a transit infrastructure monitoring project 30 years ago. The 1972 remote sensing demonstration was conducted by UMASS and the Kentucky Air National Guard to show the ability of military reconnaissance techniques to solve the problems of operating transit on surface arterials.

This appears to be the first flight of an autonomous unmanned aerial vehicle in an urban area in the United States. The imagery products will be analyzed to monitor transportation infrastructure associated with Boston's Central Artery Project (Fig. 3). The imagery also will be analyzed for application to transit infrastructure security and transit operations security. The Massachusetts Bay Transportation Authority's Deputy Chief of Police and their Special Operations personnel were briefed on the potential applications of the technology for transit operations and transit security.

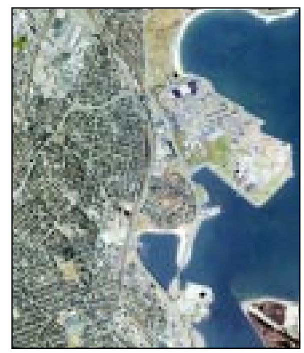

Figure 3. Flight path of an automated UAV over the multimodal transporation infrastructure, Boston, Massachusetts.

The UAV was demonstrated in an aerial survey of the changes in land use on Bridgewater State's east campus next to the new MBTA commuter rail station and also provided surveillance of the MBTA's commuter rail operations on the college campus. The MLB UAV changed mode from a computer flown right-of-way (ROW) surveillance of the commuter rail line to surveillance around a point when the commuter rail train pulled into the station.

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Foundations
for integrating imagery

The NCRST program develops and applies new analysis techniques to build the foundation for smarter imagery analysis and data reduction. The results of these developments help in building innovative tools for application to practice. Complementing traditional transportation data requirements, using advances in data and information analysis for imagery, results in better and faster project decisions at reduced costs.

NCRST investigators have developed web-based mapping and data delivery systems that are integrated with existing internet libraries and functional capabilities. The program has evolved new approaches for obtaining high levels of precision on vehicle locations and movements from airborne imagery and integrating more precise data into advanced traffic simulations. They have also designed and demonstrated algorithms that stabilize airborne video imagery so that the imagery acquired by UAVs can be used both for automatic detection of traffic flow and for human monitoring of emergency conditions. Investigators have demonstrated the application value of generic developments for imagery analysis and application to both large-scale projects and illustrative case studies that can be repeated across jurisdictions and over time. Several of these developments are unique and have significantly strengthened the foundations for imagery analysis and remote sensing technology application.

Generating geospatial data libraries needed by transportation planners

A study was performed to assess where, in what processes, and for what types of activities transportation agencies use remote sensing, geospatial, and GIS technologies so as to analyze uses, technologies, transferability, and cost/benefit to develop “best practices” about these “transportation geolibraries” and how successful implementation impacts tasks within agencies and the agencies as a whole.

Transportation agencies routinely use high-resolution remote sensing, photogrammetric, and geospatial data for transportation project assessment and planning. The nature of these data, the degree to which they are used as digital products, the

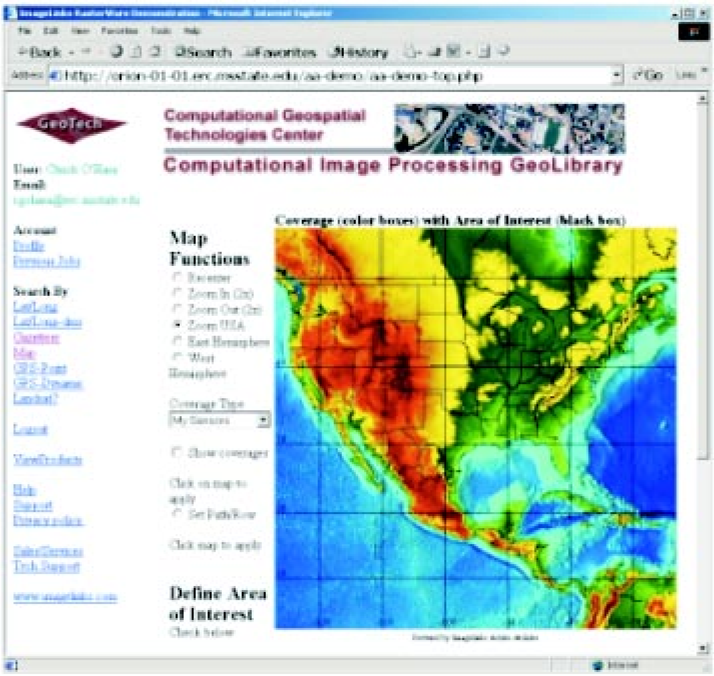

Figure 1. Interface to the MSU Computational Mapping Engine.

manner in which they are distributed and made available, the degree to which typical processing tasks are automated, and the provisions for storage and archival of investigation products and results varies significantly among various transportation agencies. Different groups within transportation agencies require data for their special needs and the data are processed to provide necessary information products. In addition, transportation agencies typically have office locations that are geographically distributed across the agency's area of responsibilities, adding further complexity to the requirement for data access, distribution, processing, version management, and archival.

Research is aimed at advanced approaches for delivering custom raster data products to end users. A NCRST team is developing an on-line computational mapping engine demonstration web site. The application is part of a larger geospatial data library effort at MSU. A preliminary demonstration of the CME's capabilities is being developed for the CSX/I-10 railroad relocation and corridor planning project that is in progress on the Mississippi Gulf coast.

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Preparing GIS data for microsimulation — a collaborative project with California DOT

Traffic microsimulation is a modern tool used by DOTs to plan road building and improvement programs, to manage congestion. A number of NCRST projects have used microsimulation to study emergency evacuation. Microsimulation models the dynamics of individual vehicles on a transportation network, taking into account roadway characteristics, such as the number of lanes and speed limit, and also the density and behavior of other vehicles. This level of modeling demands extremely detailed and accurate databases on road infrastructure, and origins and destinations, down to individual driveways. Every curve must be precisely defined in three dimensions, because curvature, slope and cross-grade all affect driver behavior. Developing this rich data base is a slow manual process, and a major impediment to the widespread use of microsimulation.

With cost-share funding from the California Department of Transportation, NCRST investigators developed a tool to translate popular ESRI® GIS files into road databases for the Paramics® microsimulation package. The challenge in conversion is that microsimulation and GIS employ different geometric models. The simulation tools are oriented towards driver behavior on straight lines and circular curves, whereas GIS deals with less predictable paths, and therefore employs a variety of methods to define geometry. Some generalization of the roadway path (which constitutes introduction of error) is necessary in the interests of computing efficiency. The effectiveness of the conversion is measured by the predictive accuracy of traffic simulations on the output databases, and computing performance.

Figure 1. Paramics® displays Los Angeles highways, easily converted from a GIS file

With the availability of this tool, it is now possible to convert GIS and even some GPS databases into microsimulation file sets instantly. In the next phase of this research, remotely sensed terrain data from IfSAR and LIDAR will be integrated into the GIS, yielding rich data bases with such information as gradient, cross-slope and forward visibility, enabling far more realistic and accurate simulation than is currently possible, better equipping DOTs for emerging traffic management demands.

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High resolution georeferencing from airborne images for traffic flow

One of the challenges of remote sensing from airborne platforms is the ability to get georeferenced images at a high resolution, but also at a sufficient sampling rate. Airborne video and still cameras can capture traffic flows much more frequently than satellite images. Analysts can use airborne images to identify individual vehicles and to track these individual vehicles over time. The challenge, however, is to find a method that captures high-resolution imagery at a high frequency and georeference the imagery at a reasonable cost.

One project, currently conducted by NCRST investigators, is examining the integration of very precise imagery with other sensors to provide georeferenced spatial coverage for vehicle tracking. In this project, a helicopter is outfitted with a differentially-corrected GPS (DGPS) receiver and an inertial measurement unit (IMU) to capture the position coordinates and roll, pitch and yaw of the helicopter. A high-resolution (16 megapixel) digital still camera and a standard digital video camera (about 0.6 megapixel) were mounted on the helicopter. At the same time, ground points were surveyed and DGPS-equipped test cars, captured in the airborne imagery, were traveling on freeways and arterial roadways in the Tucson, Arizona, area to provide the ground truth reference. The project will demonstrate the capabilities of integrating different data sources to provide very precise (under 10 cm on the ground), georeferenced tracking of individual vehicles, both spatially and temporally.

The NCRST investigators have been able to show that vehicle positions, speeds and even accelerations and decelerations can be estimated very precisely. This proof of concept has a number of interesting spin-off applications, including the following:

- This technique can provide very high resolution mapping of roadway infrastructure.
- The technique allows investigators to track vehicles more precisely than existing commercial technologies allow.
- The data collected this way can be used to better understand driver behavior in traffic, since vehicle speeds and positions, and the resulting maneuvers and the continuous trajectories can be known with high precision.
- Since many traffic agencies cannot afford high-end IMUs and high-resolution cameras, NCRST investigators are considering the potential loss of precision when lower-resolution cameras and low-cost micro-electro-mechanical systems (MEMS) IMUs are used, and the possible development of an affordable viable surveillance technology for traffic monitoring and control.

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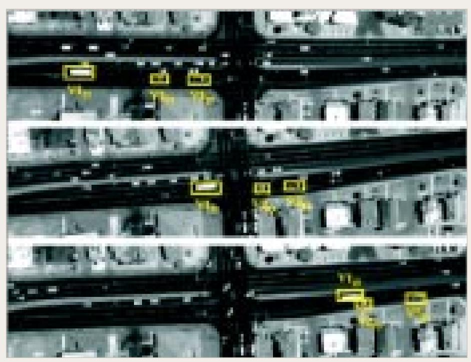

Figure 1. Three cars tracked in imagery.

Figure 2. DGPS and IMU unit mounted on helicopter.

Accessing and delivering geospatial data and toolkits for transportation applications

Remotely acquired satellite and aerial data provide input to management decisions made by public safety officers, transportation planners, resource managers, and officials responsible for securing national resources. However, discovering and accessing these data can be a daunting task that deters their use. The challenge is to provide these data and information in formats that are familiar to users and that are ingested easily into geographic information systems. The Transportation and Resource Information Management System (TRIMS), is an Internet-accessible data delivery system that provides access to data and toolkits developed specifically for transportation planners. It also offers Internet mapping services (IMS) and accesses distributed datasets with its web mapping services (WMS) capabilities.

Figure 1. TRIMS enhances decision support systems for responding to transportation emergencies.

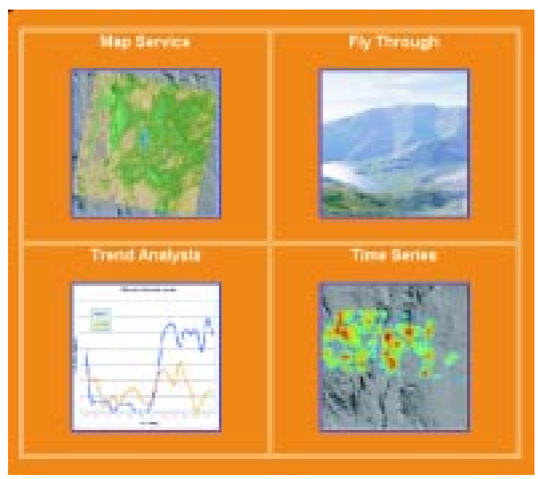

Figure 2. TRIMS tool sets available online.

TRIMS contains data that enhance decision support requirements of local transportation and resource managers. The database houses both vector and raster datasets that are downloaded and directly ingested into a desktop GIS. All files have metadata that are compliant with the Federal Geographic Data Committee standards.

User Guides describe step-by-step procedures for implementing a specific application. Sample applications give information on data sources, algorithms, analyses, and results. These models can be applied to other similar applications using data appropriate for that application. For example, the *Road Maintenance Resource Allocation Model* User Guide was developed for rural roads in McKinley County, New Mexico. The intent is that it can be used for managing road maintenance allocations in other rural areas with similar properties, such as in southern Utah.

Another feature of TRIMS is the toolkits, which provides online mapping capabilities for desktop users who are not necessarily conversant with GIS (Figure 2). Users select specific data layers from the database to construct a custom map that can be printed or downloaded to support critical management decisions. This online feature means that the user can employ GIS technology without having GIS software loaded on a local computer.

The toolkits include analytical tools such as "fly-throughs," data mining, and temporal sequences. The "fly-throughs" are animated movies that present a three-dimensional perspective of the landscape and give the viewer a sense of "flying" through the scene. This tool is useful for corridor planning, view shed analysis, and incident management.

Data mining features provide information derived from a series of datasets for a given location and present the results as a graphic representation.

Animated temporal products are available that present the user with a time-series of data for a given area and dataset. The temporal displays are useful for hourly, daily, monthly, seasonal, or annual analysis of data that provide information critical to managing transportation corridors and environmental resources.

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Automated vehicle tracking from airborne video

One of the more promising applications of remote sensing of transportation is in tracking vehicles from airborne platforms. Aircraft from fixed-wing airplanes, helicopters, or unmanned aerial vehicles (UAVs) have the capability to collect significant information about transportation infrastructure and traffic flow, over wide spatial scales. In an effort to collect and process data from these platforms, digital video can be used to collect imagery.

Figure 1. Reference frame 150, distorted frame 50, and frame 50 automatically registered to frame 150.

Ideally, a video camera attached to an aircraft would be pointing vertically down. In such a setup, the point of view of this moving camera would be similar to a fixed camera, with a consistent point of view. However, due to the roll, pitch and yaw of the aircraft as it flies, the camera tilt varies significantly between frames. This produces a significant challenge in analyzing the images, because the point of view and scale (or resolution) of the image changes continually and in somewhat unpredictable ways. In the images, this appears as a “wobble” or “jitter” between frames.

NCRST investigators are developing methods to define automatically a “fixed” point of view in video frames. The software they are developing “registers” each of the frames from the moving camera to a common point of reference. As a result, the imagery appears as if it is taken from a fixed camera, or as if the camera is pointing in a perfect vertical direction. Once this correction is made, it is much easier to extract vehicle movements (positions and speeds) automatically from the frames. So far, the method has been tested on video clips including tracking cars along an arterial roadway, along a freeway, and through an intersection while an aircraft hovers over the intersection. From these registered clips, investigators are able to measure velocities and also plot vehicle trajectories accurately.

This ability to stabilize camera images from a moving platform is a remarkable achievement and allows investigators to automate vehicle tracking. That is, once the frames are “registered,” the precise position, speed, acceleration and deceleration, and turning behavior of a vehicle can be recorded automatically from the frames. Besides the expected benefit of monitoring traffic flows and evaluating the level of service for the freeway, arterial, and intersection under surveillance, this ability provides a valuable resource for investigators and model builders in understanding driver behavior and the resultant vehicle movement.

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Outreach for marketing products AND RESULTS FOR GLOBAL COMPETITIVENESS

A priority objective of the remote sensing technology applications program is to achieve transfer of products and results to transportation users and to promote a dialogue for designing new applications for meeting transportation requirements. The outreach process also helps in professional building of the transportation workforce on emerging technology application using remote sensing tools and services. National and international outreach on program results and products are important components of the program. The international outreach generates new opportunities for global marketing of results applied to transportation services practice.

The NCRST program conducted a number of workshops for outreach focused on groups of transportation and remote sensing specialists, on potential payoffs of remote sensing application and developing guidelines for application to practice. These outreach meetings with transportation practitioners have significantly helped the state agencies to implement products and results emerging from the program. These outreach efforts and demonstrations helped NCRST researchers to identify specific challenges for application to practice, and to design application solutions for remote sensing technology application in areas such as corridor planning and environmental assessment, wetlands identification, integration with intelligent transportation systems, and transportation security. Several international outreach meetings were held to explore global marketing of products and results emerging from the program. The international outreach activities with China, India, Hungary and Germany were specifically productive in developing a joint framework for transfer of U.S. remote sensing products and results to meet national transportation needs in these countries.

Expert workshop on using remote sensing and geospatial technologies for corridor planning and environmental assessment activities

The Geospatial Information for Corridor Analysis and Planning workshop (GICAP 2002) was held as part of the Technical Outreach efforts of NCRST. The goal of the workshop was to explore how geospatial information of various types could be appropriately used to impact important issues in transportation corridor planning and environmental assessment. The workshop included invited presentations from researchers, project managers, geospatial data providers, environmental analysts, and decision makers. The workshop goal was to distill common issues and challenges in corridor assessment and planning and match those issues and challenges with relevant geospatial information and geospatial data processing and analysis algorithms.

Topics and presentations ranged geographically and by transportation modes, including such diverse areas as the Alaska Natural Gas Pipeline, the Virginia Base Mapping Project, and the Mississippi Gulf Coast CSX Railroad relocation project. The workshop results will assist NCRST in formulating and prioritizing future research activities.

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Figure 1. Alaska Natural Gas Pipeline.

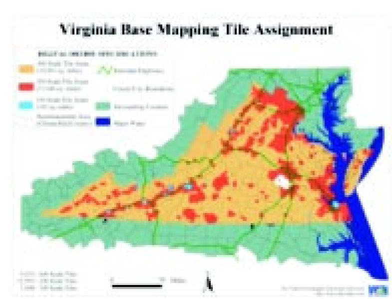

Figure 2. Virginia Base Mapping Tiling Assignment.

Teaming with DOTs, data providers, and resource agencies for improving the confidence of using remote sensing and spatial technologies for estimating wetland impacts

For an area in Randolph County, North Carolina, a NCRST-sponsored TAP collected high-resolution hyperspectral image data and LIDAR elevation data. The study area location was between Asheboro and High Point, North Carolina in the Deep River watershed. The NCRST team and the TAP as a research partner developed data fusion techniques, data stratification techniques, contextual analysis methodologies, and an algorithm for assessing the likelihood of wetlands occurrence.

For the application developed in the North Carolina project, LIDAR elevation data and hyperspectral image data were used to provide improved information about the location and distribution of wetland vegetation as well as hydrologic and soils conditions for the area. Similar data have been collected for a second location in Eddyville, Iowa to determine if the approach developed in North Carolina can help the Iowa DOT find the best location for a bypass project that will likely be located in and around environmentally sensitive areas.

The Virginia DOT is conducting a project to determine the usefulness of integrating multispectral imagery into everyday workflows for the wetland identification process. This approach will demonstrate how the integration and application of remotely sensed data into the existing enterprise GIS architecture at VDOT can benefit the department by assisting in the planning process and streamlining some of the steps involved. Through the implementation and utilization of multispectral imagery, the automation of classification procedures to generate GIS polygon data of wetland sites, and

Figure 1. US DOT RSPA EarthData Study Area - High Point, Randolph County.

the integration of this data with numerous GIS data layers into the enterprise GIS architecture, the entire complex process has the potential to be streamlined and enhanced with remote sensing data.

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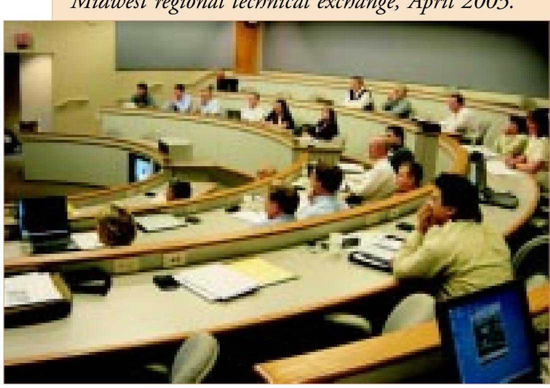
Midwest regional technical exchange

In August 2001, NCRST conducted an outreach meeting in association with the Transportation Research Board. Photogrammetry staff from three Midwestern state DOTs, Iowa, Minnesota and Wisconsin, met in Decorah IA for a one-day technical exchange meeting. DOTs reported on their activities in remote sensing and photogrammetry. With the help of NCRST experts, they identified key research requirements, notably scientific documentation of LIDAR accuracy, comparison of LIDAR with photogrammetry for specific applications, and results of nested technologies that blend LIDAR with photogrammetry. Consortium members designed research projects around these requirements. A follow-up two day meeting was held in Madison WI in April 2003, with seven states in USDOT District 5 (i.e. Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio and Wisconsin) to report on the research findings, and to review progress of the DOTs. This meeting focused on technology transfer of airborne and ground-based spatial sensing technologies such as softcopy photogrammetry and LIDAR for transportation infrastructure projects.

Midwest regional technical exchange, April 2003.



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FAA meets with NCRST on enhancing safety of U.S. airports

Members of NCRST and several commercial partners met with Federal Aviation Administration (FAA) administrators in Oklahoma City to demonstrate remote sensing applications for airfield obstruction identification and airfield safety.

The growing number of obstructions surrounding modern airports compromises aircraft (and public) safety (Figure 1). The FAA requires regular ground surveys of every U.S. airport to collect current obstruction information for pilots and airport managers. Due to limited resources and the large number of airports that must be surveyed, this process is behind schedule.

Remote sensing techniques provide faster and more comprehensive multipurpose data that can be incorporated readily into systems for identifying obstructions and mapping facilities. Effective airport safety and management requires the accuracy and timeliness provided by imagery and image data.

Presentations made to FAA included:

- The Santa Barbara Municipal Airport study comparing the effectiveness of LIDAR and aerial photography for identifying glide path obstructions and for assessing facilities management applications.
- A demonstration of ClearFlite™, an automated obstruction identification software package (Figure 2).
- An image-based 3-D solid terrain model derived from imagery and other geospatial data that illustrates the FAA-defined surface identifying obstructions surrounding airports (Figure 3). This full color, high-resolution model provided a new perspective of the obstruction identification process for FAA personnel.

The NCRST/FAA meeting led to a discussion on efforts using other remote sensing technologies and explored the possibility of developing a test bed airport for assessing remote sensing applications in airport safety, planning, and management. Dialog continues between the FAA, the Santa Barbara Municipal Airport, and NCRST to implement these applications.

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Figure 1. Obstructions are increasing at the nation's airports.

Figure 2. Software demonstration to FAA.

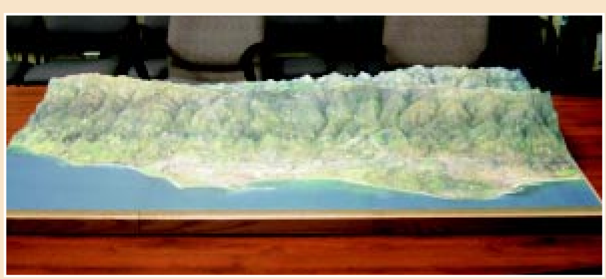

Figure 3. 3-D solid terrain model of Santa Barbara Municipal Airport.

Protecting America's critical transportation infrastructure by preparing for the unknown

Protecting the U.S. transportation infrastructure is a major challenge. How do planners prepare and pre-empt terrorist attacks on America's transportation lifelines to maintain commerce and protect people? Preparing for future attacks on our critical transportation infrastructure requires advance planning to detect, protect, prevent, respond, and mitigate incidents whenever and wherever they occur. NCRST has a key role in helping to secure America's multi-modal lifelines by providing regional, state, county, and municipal authorities with straightforward methods for using sensor and image-derived intelligence from multiple sources. At the national level NCRST can provide technical input to ensure that such intelligence is interoperable with a variety of scaleable geospatial databases.

As a result of the critical need to bolster homeland security NCRST held two workshops in 2002 centered on using remote sensing and other geospatial technologies to support transportation security. The first report is available online at: http://trans-dash.org. Its most important findings were:

- Geospatial tools should be a major component in efforts to improve transportation security, particularly in assessing critical infrastructure vulnerability and in planning for mitigation and response to terrorist attacks.
- The U.S. must develop an accessible geospatial infrastructure corresponding to, and compatible with, the nation's transportation infrastructure. This geospatial infrastructure should reflect all elements of the transportation infrastructure, including detailed information on the location, context, structure, and condition of these elements.
- Databases and other information developed to improve transportation security must be interoperable among agencies and political jurisdictions.

The second transportation security workshop focused on transporting hazardous materials. Some of the more common and familiar transport items that move through thousands of urban centers daily, such as gasoline, chlorine, and industrial explosives, pose special risks to U.S. security. Remote sensing, coupled with GPS, GIS, and intelligent transportation systems, has a significant role in these security issues for all phases of the challenge, from threat detection to response and recovery after an attack.

These concerns extend to security for the entire intermodal transportation network. Approximately 5 million containerized freight shipments move through America's ports each year, creating a significant challenge to U.S. security. After arriving on U.S. shores they are loaded onto trucks and rail cars and shipped throughout the country. Future remote sensing technologies will assure that these containers do not hold security threats and will arrive safely at their destinations. A demonstration of a pulsed laser imagery capable of detecting minute amounts of volatile gases in the atmosphere holds promise for checking containers remotely for traces of potentially hazardous chemicals and bioagents.

Recommendations stemming from these workshops included a proposed 15-year road map addressing near-, mid-, and long-term solutions (see report at http://trans-dash.org). It was also recognized that geospatial data and information tools are needed for improving transportation security. These tools include software and methodologies for safety, hazards, and disaster assessment, environmental assessment, traffic flow, and infrastructure planning.

State DOTs and public safety officials are already adopting relevant parts of the road map, but at different levels of intensity. Most are assessing their existing assets and financial resources for implementing a broader program. Many are addressing specific, high-priority issues.

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Workshop on integrating remote sensing and intelligent transportation systems technologies for transportation flow

Effective operation of intelligent transportation systems (ITS) requires wide-area, real-time data, some of which is difficult and expensive to acquire from the usual array of ground-based detectors. Remote sensing technologies (RST) may provide an innovative means of obtaining the requisite data. NCRST held a workshop in July 2002 to identify opportunities for synthesizing RST and ITS data. Specific workshop objectives were to characterize the state-of-the-art and identify research, development, and demonstration (RD&D) needs for RST to succeed in this application area, and to identify education, training, and technology transfer needs for lowering the barriers to RST applications in ITS. The workshop attracted 40 participants, approximately equally divided between the ITS and RST communities.

Several significant issues were addressed by experts at this workshop for RST to be able to provide real time (or near real time) system-wide monitoring. The unstated requirement is that this monitoring should be conducted at a scale that allows for the identification of vehicles and vehicle types (trucks *vs.* cars), and yet provide a geographic coverage that may extend from the urban core to the entire metropolitan area. Promising high-yield applications identified for RST included data collection in rural areas that lack traffic sensors, and collection of data for verification and validation of traffic models. Concerning data collection platforms, there was considerable interest in applying results from exploratory trials carried out by using unmanned aerial vehicles (UAVs) for real-time traffic management, incident verification, and tracking particular vehicles.

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Remote sensing helps in the monitoring of traffic flows.

Reaching out for global remote sensing of transportation flows in Germany

The USDOT co-sponsored the International Workshop on Satellite Based Traffic Measurement, held 9-10 September 2002 at the German Aerospace Center's Institute for Transport Research in Berlin, Germany (see http://www.ncrst.org/research/ncrst-f/projects/workshops.html). During this workshop, NCRST signed a Memorandum of Understanding with the

German Aerospace Center to collaborate on remote sensing of traffic flows. Immediate steps included planning for a visit of a German scientist to the U.S. and the presentation of the results from the workshop at the Annual Meeting of the Transportation Research Board (TRB) in January 2003.

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Reaching out for global service competitiveness in India

India poses unique challenges and opportunities for NCRST. Like much of Asia, its transportation problems are closely interwoven with rapid social and economic development over the last two decades. It has a rich base of technical expertise, even its own remote sensing satellites. Thus it poses particularly complex problems, and offers rewarding research collaboration opportunities.

Figure 1. A completed section of the Golden Quadrilateral highway system, between Bombay and Pune.

The National Highways Authority of India (NHAI) is engaged in the National Highway Development Program (NHDP), developing 14,000 km of existing 2-lane highway into 4- and 6-lane freeways, to be substantially completed by 2003. NHAI is in need of advanced technologies in planning, design and construction, and is also interested in state of the art asset management and operational methods. NCRST has signed a Memorandum of Understanding (MOU) with the NHAI, to exchange expertise in a wide range of technical areas, from pre-construction aerial survey and mapping to precision construction, microsimulation and road information systems. NCRST is working with the Central Road Research Institute, the Indian Institutes of Technology, the Indian Space Research Organization's National Remote

Figure 2. Opening session of Map India 2003.

Sensing Agency, and other centers of local expertise, to collaborate on methodological issues, and to build a community of providers and users of spatially oriented transportation technologies.

NCRST jointly organized a seminar on spatial technologies in transportation in conjunction with the Map India international conference in New Delhi (28-31 January 2003). More than 400 Indian, U.S. and international participants attended.

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Reaching out for global service competitiveness in India and Asia

A workshop is planned for 27-29 March 2003, in collaboration with the Indian Department of Space/ National Remote Sensing Agency, in Hyderabad, India. Three topics have been identified for collaboration: the Golden Quadrilateral, Rural Road Connectivity, and remote sensing/ geographic information system applications in urban transportation problems. The Golden Quadrilateral consists of the design and building of a modern superhighway, using the latest in ITS (intelligent transportation systems) technology, connecting the four major metropolitan centers in India, as part of its primary highway network. The primary/ secondary highway network in India has severe capacity constraints and a lack of mobility. The current plan of the Indian government also calls for connecting every village of 250 or more residents with an all-weather road, as part of its tertiary road. Today 40% of the rural population is without all-weather connectivity. This obviously calls for environmental and infrastructure planning, as well as careful consideration of the flows expected over the designed network. This major activity will influence rural growth patterns in the future, as it will enable, for the first time, the potential marketing of all agricultural products, including perishable goods, beyond the immediate region.

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Remote sensing technology for transportation in China

A Joint China/NCRST Coordinating Committee initiated discussions in late 2001 to explore collaborations that apply remote sensing technology to transportation problems in China. These discussions culminated in a joint two-day workshop held in Beijing in December 2002 to determine how state-of-the-art remote sensing and geospatial technologies could help in three high priority transportation issues:

1. Infrastructure and security planning for the 2008 Summer Olympics in Beijing

2. Corridor planning for China's National Trunk Highway (CNTH) system, pipeline routing, and railroad routing

3. Detecting, monitoring, and mitigating landslides, and planning population relocation in the Three Rivers Gorge region of the Yangtze River Valley.

Figure 1. Participants in the China-USA Workshop on Remote Sensing and Geospatial Technology Applications for Transportation.

A draft Memorandum of Agreement (MOA) is under review by the U.S. and People's Republic of China that would enable technical exchanges of people, methodologies, and non-sensitive technologies on a project-by-project basis.

NCRST, the Chinese Academy of Transportation Sciences (CATS), and the Chinese Academy of Sciences-Institute of Remote Sensing Applications (IRSA) will implement the MOA.

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Reaching out for global transportation service competitiveness in Hungary

DOT co-hosted the International Workshop on Commercial Remote Sensing and Spatial Information Technology Applications to Transportation, held 13-14 September 2002 at the Budapest University of Technology and Economics (BUTE) in Budapest, Hungary (see http://www.ncrst.org/research/ncrst-f/projects/workshops.html).

The goal of the workshop was to bring together invited researches, as well as research program managers from various government agencies in the United States and Central Europe, to discuss ongoing research and new remote sensing technologies. Sessions on airborne congestion surveys, remote sensing and intelligent transportation systems, traffic monitoring, other modes, methodological issues, and clearinghouse and data issues had invited speakers from both Europe and the United States. In addition, developing a collaborative R&D agenda for the future, through various panel discussions, was a key objective of the workshop.

A draft Memorandum of Understanding between NCRST and BUTE will be circulated to the Hungarian Ministries of Communication and Transportation, at the request of these agencies, to provide the basis of a possible Memorandum of Agreement between USDOT and these two agencies.

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PARTNERSHIP PROJECTS FOR MULTIMODAL TRANSPORTATION APPLICATIONS

ENVIRONMENTAL IMPACT FOR MULTIMODAL CORRIDOR PLANNING CONSORTIUM

Mississippi State University, Lead
www.ncrste.msstate.edu

Dr. Roger King, Consortium Manager
Dr. Charles 'Chuck' O'Hara, Consortium Coordinator

Streamlining the decision process for corridor planning and relocation

- New solutions for transportation relocation and corridor planning.
- Using raster and vector geospatial data in corridor planning.
- Relocating the CSX railroad in the Mississippi coastal corridor.
- Assessing urban growth in coastal corridors.
- LIDAR applications for terrain mapping and hydrologic analysis.
- LIDAR application for alignment optimization.
- Hyperspectral data for wetland vegetation mapping and analysis.
- Geospatial data fusion for environmental assessment.
- Analysis of growth impacts on urban watersheds.
- LIDAR measurements of air pollutants and air quality modeling.
- Assessing urban growth and transportation impacts .
- Mapping resources and data libraries for environmental assessment.
- User needs for geospatial technologies.

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Auburn University
USRA
NASA Marshall Space Flight Center
Digital Globe
Intermap Technologies Corp.
Earth Data Technologies, LLC
ITRES Corporation
Virginia DOT
EarthData
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Washington State DOT
Veridian Systems Division

DISASTER PREPAREDNESS AND LIFELINES SECURITY CONSORTIUM

University of New Mexico, Lead
www.trans-dash.org

Dr. Stanley Morain, Consortium Manager
Dr. Richard P. Watson, Consortium Coordinator

Hazards, disasters and security response

- Planning evacuations in emergencies.
- Detecting damaged bridges for emergency response.
- Planning community evacuations for large populations.
- Tools for managing highway bridges.
- Transportation hazards consequence tool.
- Geospatial data and toolkits for transportation applications.
- Rational Mapper—a tool for processing high-resolution images.
- Assessing pipeline and airport safety using LIDAR data.
- Hyperspectral analysis of urban surface materials.
- Evacuation routing tools to reduce evacuation times.
- Evacuation simulations for communities trapped in a bottleneck.
- Mapping potential damage due to land subsidence.
- Sensing technologies for planning pipeline corridors.
- Managing rural roads in Indian reservations.
- Calculating mileages for highway performance monitoring.
- Safety obstructions at Municipal Airport.
- Weather-related road hazards assessment.
- High-resolution satellite data updates E-911 road information.

University of New Mexico
University of Utah
Oak Ridge National Laboratory
George Washington University
York University
ImageCat, Inc.
DigitalGlobe
AERIS Inc.

INFRASTRUCTURE ASSET MANAGEMENT AND SAFETY CONSORTIUM

University of California Santa Barbara, Lead
www.ncgia.ucsb.edu/ncrst

Dr. Michael Goodchild, Principal Investigator
Dr. Val Noronha, Project Director

New solutions for infrastructure asset management

- Responding to security threats, hazards and disasters.
- Evacuating a small neighborhood: infrastructure adequacy.
- Meeting the challenge of inventory assessment.
- Urban hyperspectral sensing and road mapping.
- LIDAR applications for highway design and construction.
- LIDAR for engineering design.
- BridgeView – a tool for bridge inventory and assessment.
- Security siting of off-port inspection facilities.
- Tools for managing highway bridges for the National Bridge Inventory.
- Aviation infrastructure planning and development support.

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Geographic Paradigm Computing Inc.
Florida DOT
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Tetra Tech, Inc.

MULTIMODAL TRANSPORTATION FLOW CONSORTIUM

Ohio State University, Lead
www.ncrst.org

Dr. Joel L. Morrison, Consortium Director
Dr. Mark R. McCord, Consortium Research Coordinator

Integrating remote sensing for transportation operations

- Real-time bus information system with image backdrops.
- Applications for traffic operations.
- Traffic measures using satellite and airborne imagery.
- Determining highway level of service using airborne imagery.
- Improving freight flow flow management.
- High resolution georeferencing from images for traffic flow.
- "Bird's-eye" views of networks for mitigating urban congestion.
- Exploring LIDAR applications for traffic flow.
- Pioneering traffic data collection from UAVs.
- Automated vehicle tracking from airborne video.
- UAV applications for multi-modal operations.
- Airborne Data Acquisition System (ADAS) for traffic surveillance.

The Ohio State University
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