Achievements
of the DOT-NASA Joint Program on Remote Sensing and Spatial Information Technologies
Application to Multimodal Transportation

Environment

Flows

Infrastructure

Hazards

2000–2002

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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This report presents three-year accomplishments from the national program on Commercial Remote Sensing and Geospatial Technology (CRSGT) application to transportation, administered by the U.S. Department of Transportation (U.S. DOT) in collaboration with the National Aeronautics and Space Administration (NASA). The joint program was authorized under Section 5113 of the Transportation Equity Act for the 21st Century (TEA–21). This is the first national program of its type focusing on transportation applications of emerging commercial remote sensing technologies.

U.S. DOT's Research and Special Programs Administration manages the program in coordination with NASA's Earth Science Enterprise's application programs. The program focuses on applications of CRSGT products and systems for providing smarter and more efficient transportation operations and services.

The program is performed in partnership with four major National Consortia for Remote Sensing in Transportation (NCRST). Each consortium focuses on research and development of products in one of the four priority areas for transportation application, and includes technical application and demonstration projects carried out in partnership with industries and service providers in their respective areas.

The report identifies products and accomplishments from each of the four consortia in meeting the goal of providing smarter and more efficient transportation services. The products and results emerging from the program are being implemented in transportation operations and services through state and local agencies.

The Environmental Assessment and Application Consortium (NCRST-E) provides leadership for developing and deploying cost effective environmental and transportation planning services, and integrates CRSGT advances for achieving smarter and cost effective corridor planning.

The Infrastructure Management Consortium (NCRST-I) provides leadership in technologies that achieve smarter and cheaper ways of managing transportation infrastructure assets, operation, and inspection, and integrates CRSGT advances for achieving infrastructure security.

The Traffic Flow Consortium (NCRST-F) provides leadership to develop new tools for regional traffic flow management including heavy vehicles and intermodal flow of freight, and integrates CRSGT advances for complementing and extending the reach of ITS user services.

The Safety, Hazards and Disasters (NCRST-H) provides leadership for deploying remote sensing technology to locate transportation hazards and improve disaster recovery, and integrates CRSGT advances for application to protect transportation systems from terrorism.

The DOT-NASA team is proud to present this report of accomplishments on products and results emerging from the joint program for application to transportation practice.

Dr. K. Thirumalai
Program Manager

Environmental

ASSESSMENT, INTEGRATION AND STREAMLINING

The **NCRST–Environment** (NCRST-E) Consortium focuses research on the goal of providing cost effective corridor assessment and planning tools. NCRST-E is a consortium of academic, government, not-for-profit, and commercial partners with common goals of:

- Developing innovative remote sensing technology solutions for use in transportation environmental assessment and planning and by applying the capabilities of new high spatial resolution, multispectral and hyperspectral instruments;
- Developing the tools necessary to extract environmental information efficiently from remote sensing;
- Streamlining and standardizing data processing for information necessary to expedite NEPA environmental assessment requirements; and
- Expanding awareness and understanding of the value of remote sensing technology to transportation environmental professionals by outreach, training and education.

NCRST-E research applies remote sensing imagery of increased spatial, radiometric, and temporal resolution to the analysis of transportation impacts on the environment, both natural and man-made. The research areas of the NCRST-E include needs assessment for remote sensing information in transportation environmental assessment; land cover classification and change detection; wetlands mapping and assessment; air quality measure-

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ment, analysis, and modeling; watershed assessment and characterization; habitat assessment; cultural feature identification; and digital geospatial libraries for environmental assessment and planning in transportation.

Remote sensing allows for the synoptic observation and analyses of urban growth. Satellite images with moderate resolution (10 to 30 meters) have for decades facilitated scientific research activities at landscape and regional scales. Recent availability of satellite- and aerial-based imaging systems data that provide spatial resolutions of 1m or better facilitates analyses that can applied to urban growth and transportation development for site specific investigations. Moreover, new hyperspectral sensors provide increased spectral resolution that can be used to further the analyses of environmental conditions and how urban growth and associated transportation development impact these conditions.

In its Strategic Plan for Environmental Research, the Federal Highway Administration (FHWA) has a strategic goal to "Protect and enhance the natural environment and communities affected by highway transportation." The growth of transportation networks generates a host of environmental impacts ranging from deforestation, impacts on local and regional hydrology, and accentuation or enhancement of such land-atmosphere factors as the urban heat island phenomenon. Performance indicators and metrics have been developed for such areas as community satisfaction, EPA ratings of FHWA Environmental Impact Statements (EIS),

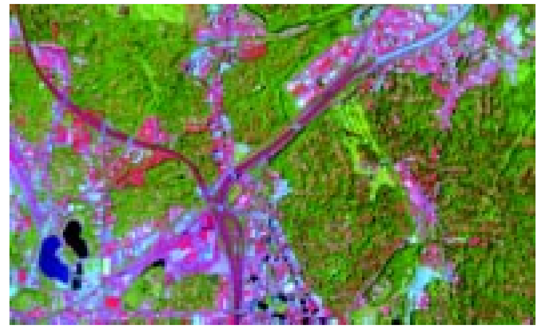

Figure 1. New sources of high resolution satellite image data may provide improved ability to conduct site specific investigations for transportation assessment and planning.

on-road mobile emissions, percent of non-attainment and maintenance areas meeting mobile source emission budget goals, and ratio of wetland replacements from Federal-aid projects. Matching research and technical outreach to these strategic objectives, and measuring research performance results are tasks fundamental to the mission of the NCRST-E.

The focus of the consortium's activities in future years is expected to include increased participation in transportation corridor assessment and planning with particular emphasis on the application of geospatial technologies that impact these processes. To that end, the consortium is currently conducting technical outreach activities with transportation agencies on specific projects and is planning a workshop for August of 2002 that will focus on "Geospatial Information for Corridor Assessment and Planning" (GICAP). The GICAP workshop will invite participation from engineers, analysts, planners, and managers who are working on projects for specific high-interest transportation corridors including I-10, I-69, I-95, Atlanta and Chicago corridors, and the Alaska Gas Pipeline Corridor.

Figure 2. (a) Classification product, (b) high resolution (1m) hyperspectral image data, (c) composite land cover classification.

Figure 1. Satellite image data of the Mississippi coastline used for regional assessment and land cover and land use change analysis.

Mississippi I-10 Coastal Change and Corridor Assessment and Planning

The three coastal counties in Mississippi have undergone considerable change in land use, population, wildlife habitat, demographics, and socio-economic conditions in the past 30 years. In that time, Interstate 10 (I-10) has been completed, extensive population growth has occurred, and the coastal counties have changed from being mostly small fishing and shrimping communities to communities with a complex mixture of residential, commercial, industrial, urban, resort, and relatively unspoiled coastal wilderness areas. The population has gone from around 240,000 in 1970 to more than 350,000 in 2000.

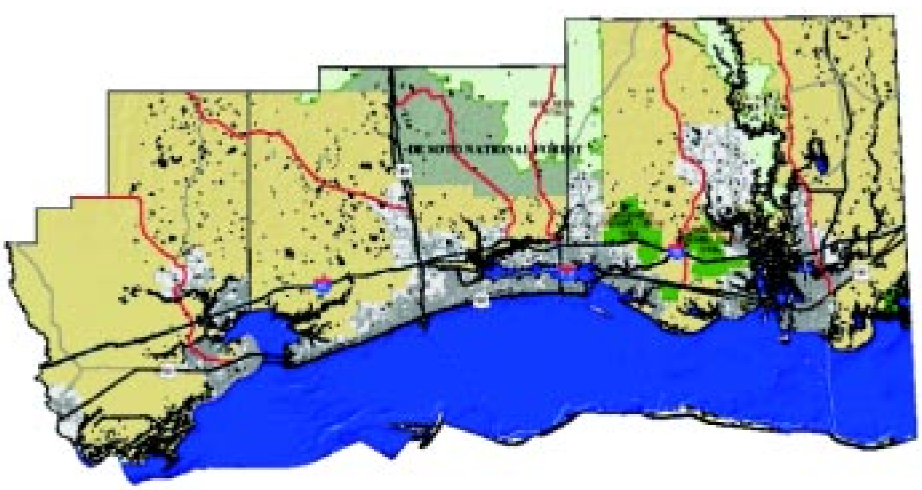

Figure 2. Location of the Mississippi I-10 coastal change and corridor assessment and planning effort.

NCRST-E studies of the Mississippi coastal corridor have highlighted significant changes and development that have occurred in the past 30 years that include population growth, the building of Interstate-10, and rapid growth of the tourism industry in the region. NCRST-E has conducted studies using GIS data, historical satellite imagery, and existing aerial image data to assess changes in the area. Initial exploratory comparative analysis of existing land cover classification data for the area compiled at various times over the past 30 years provided results that were not adequate for the identification of development trends or for spatial characterization of land

Figure 3. (a) High-resolution 5m elevation data, (b) 30 m satellite image, (c) hillshading using elevation data improves visualization of image.

cover and land use change. However, image and change detection analyses performed on satellite images scenes acquired for the area for the past 30 years provided valuable insight as to development patterns and trends, while also indicating areas where future growth patterns may cause potential stress on sensitive wildlife habitat areas.

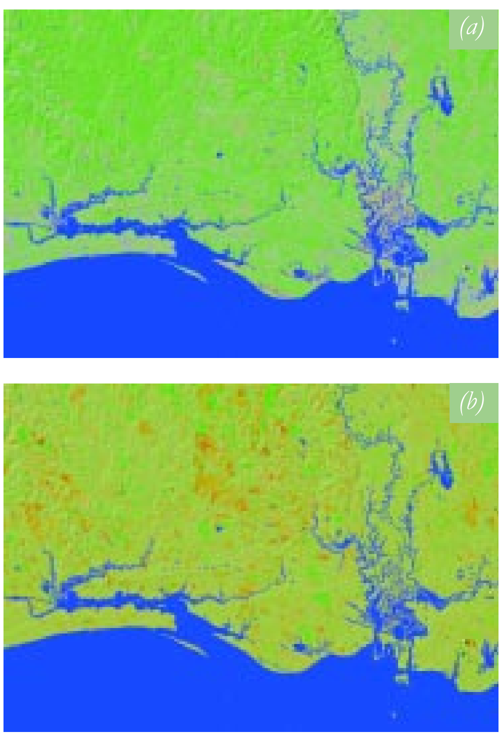

Figure 4. (a) Satellite image data were processed to produce Normalized Difference Vegetation Index (NDVI) maps for 1990 and 2000 as an indication of vegetation coverage. (b) Change in NDVI can provide a good indication of land cover change and urban development.

These studies have illustrated the need to update information resources so that improved information will be available to those who make decisions about future growth and development for the region.

After the inception of NCRST-E project efforts, significant interest has been focused on the proposed relocation of the CSX railroad from its current location. The CSX railroad currently runs through the center of high growth areas along the shore, and the proposed move would provide a high-speed rail running east-west along a more inland route, potentially farther north than the I-10 corridor. A project has been funded by the Congress as part ofthe DOT Joint Program, to conduct the environmental assessment for the CSX relocation project with the requirement that the assessment make broad use of remote sensing and geospatial technologies.

The project is managed by DOT/RSPA in coordination with FHWA and Mississippi Department of Transportation (MDOT), USDOT and NASA and is intended to help bring these technologies into mainstream practice.

As part of the project, NCRST-E will support the environmental assessment of the CSX railroad relocation and I-10 corridor study by providing technical assistance in the selection and use of appropriate remote sensing and geospatial technologies to the team selected by the Mississippi Department of Transportation and the Federal Highway Administration to conduct the study. NCRST-E will also provide a compilation of existing appropriate remote sensing and geospatial data and information resources for the study through an on-line web-mapping portal that will include new data collected for the area and data collected during the assessment process.

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Environmental Impacts Assessment of Land Cover and Socioeconomic Changes at the Watershed Scale in Metropolitan Atlanta

Development of transportation networks can engender 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 watershed scale by analyzing the relationships between anthropogenic factors and hydrologic indices. The hydrologic indices selected were mean annual flow, frequency of inundation above specified levels, and corresponding duration of inundation. They were selected due to their close relationship with environmental issues such as wetlands identification, habitat maintenance, and flood plain analysis. The study focuses on two small urban watersheds in the metropolitan Atlanta, GA area (Sope Creek and Big Creek). Remotely sensed data taken at various spatial and spectral scales were used to map land cover changes over the basins for a period extending from approximately 1975 to the present. Socioeconomic and population demographic data were obtained from census and business records for the appropriate counties. These data were projected onto the watershed surfaces in point vector format so that spatial locations could be accurately determined from census tracts and post office zip codes. The population centers for the Big Creek watershed, based on data from the latest census, are shown in Figure 1. As shown in Figure 2, the overall population of the Big Creek watershed has increased by over 500% over the past four decades with the most dramatic increase coming in the period since about 1985. The commercial database showed that the most rapid increase in business activity has been in the past five years with

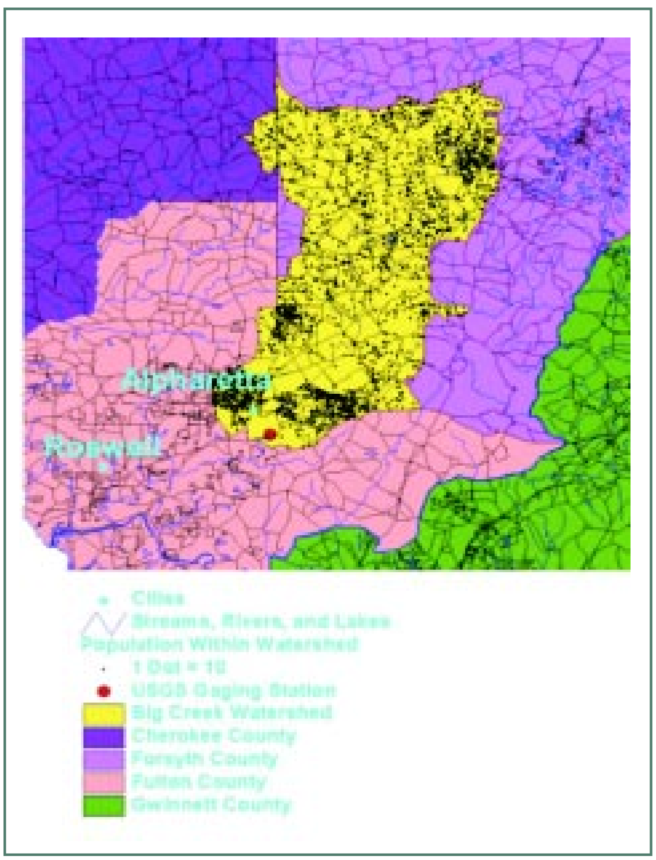

Figure 1. Population centers for Big Creek watershed based on 1990 census.

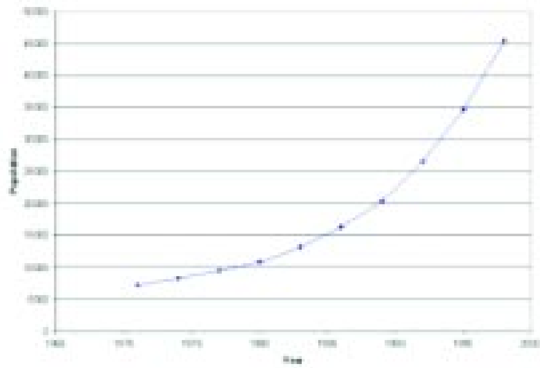

Figure 2. Population increase in Big Creek Watershed (1965-98).

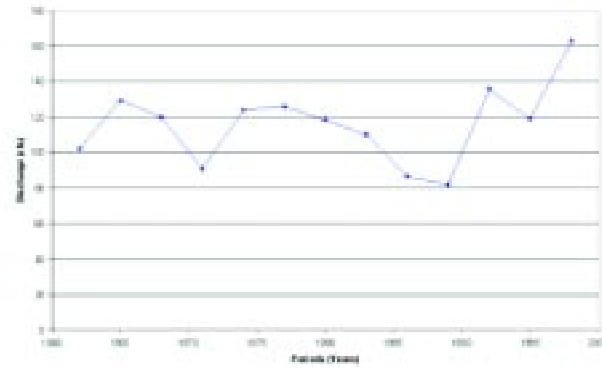

Figure 3. Running three year average flow for Big Creek Watershed (1960-98).

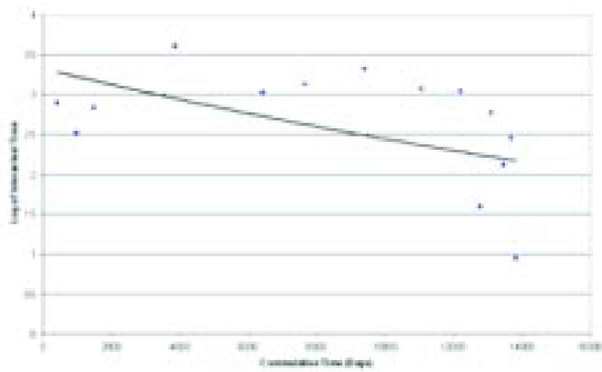

Figure 4. Interarrival times of events above 2000 CFS.

732 new businesses established in that period, representing 46% of the total businesses in the watershed.

Streamflow records were obtained from the U.S. Geological Survey database and were used to derive the various hydrologic indices used in the analysis for the period of record. For example, Figure 3 shows a running average of the mean annual flow for Big Creek for the period 1965-98. The figure demonstrates that beginning in the late 1980s, mean flow has increased by roughly 60 per cent. Of course, this period corresponds approximately with the time when the population and associated commercial activity began to dramatically increase in this basin as shown in Figure 2. 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. Figure 4 then demonstrates that the time period between the larger individual streamflow events has been decreasing very significantly in that same time period indicating that flooding now occurs more frequently in this basin than in past decades. Analysis of the rainfall records at the Atlanta Hartsfield Airport revealed that there has not been any significant increase in rainfall in the city during the past twenty years.

Linear regression analyses showed that trends in population increase and business activity were closely related to increasing mean flows, increased frequency of inundation, and increased duration of inundation of the test watersheds. The level of significance of these tests ranged from 0.002 for population versus mean flow to 0.101 for frequency of inundation versus population. Thus, statistically significant relationships were established in each case.

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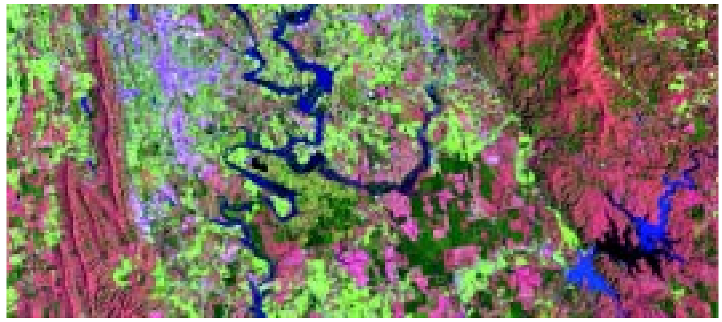

Figure 1. A false-color Enhanced Thematic Mapper Plus image of an area northeast of Atlanta, GA showing a mix of managed forests, agricultural and developed land in a region of complex physiography.

Use of Remotely Sensed Landcover Information in Streamlining Transportation Corridor Planning and Environmental Assessment in Metropolitan Atlanta

Transportation agencies at all levels are facing unprecedented pressures to fulfill new missions and to take on additional responsibilities in their role to preserve and develop new transportation systems. The need for innovation in all aspects of transportation systems has never been greater. Land use and land cover (LULC) information is paramount in transportation planning and environmental monitoring, management and assessment. Multispectral remote sensing represents a technology that has not been widely exploited in the transportation industry.

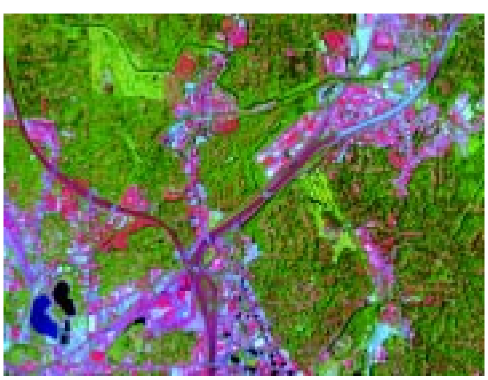

Figure 2. High-resolution imagery can be used in assessing the interaction between the human and natural environment and planning future development.

Current land use information is essential to effective planning of new transportation corridors, to forecast environmental changes, and to monitor these changes over time. Historically, land use information has come from land records or site surveys, aerial photography, and satellite remote sensing. Satellite remote sensing data can be more effectively used in the planning of new or expanded transportation corridors and in the assessment of environmental change over various time scales. The availability of these data across time scales makes it a highly desirable resource in comparison to site surveys or aircraft data. Data resolution has historically been the major drawback to using satellite data more extensively for regional and especially local planning purposes. However, use of satellite data is becoming more practical for transportation corridor planning as data resolution and analytical techniques improve. Current research indicates that while higher resolution satellite data will improve the accuracy and specificity of land use updates, ancillary data sources will still be needed to complement the image interpretation process.

Urban growth and sprawl have been attributed to a number of cultural and economic conditions, one of which is highway development. A prevailing conundrum is whether highway development initiates urban growth and sprawl, or whether urbanization and the concomitant expansion of suburban "bedroom" communities into rural areas precipitates transportation improvement or development. Regardless, the growth of transportation networks associated with urban growth and sprawl translates into a host of environmental impacts: deforestation, impacts on local and regional hydrology, and accentuation or enhancement of such land-atmosphere factors as the urban heat island phenomenon. The most notable effect that urbanization has on the local or regional environment is LULC changes. Highway development undoubtedly contributes to significant changes in LULC, and this is most obvious as it contributes to urban sprawl. In turn, changes in urban LULC have profound effects on the environment.

Two studies were conducted to demonstrate how land cover information is derived from satellite data, and how this information can be used in streamlining corridor planning and environmental assessment in two regions undergoing rapid development. The transportation system is assessed in the overall context of land cover, hydrologic, and socioeconomic change. One of these regions is in the southern Appalachian region of northern Alabama and Georgia, and the other region is along the coastal plain of southern Mississippi. Physiographically distinct, these areas have undergone considerable population growth in the past 30 years with corresponding change in demographics and socioeconomic conditions.

Growth of the Atlanta, GA metropolitan area since the early 1970s to the present, has impacted meteorology and air quality of the region. The population of the Atlanta metropolitan area increased by 27% between 1970 and 1980 and 33% between 1980 and 1990. Concomitant with this high rate of growth has been a rapid expansion of the highway system in the Atlanta area to accommodate this burgeoning population. This has resulted in tremendous LULC changes within the metropolitan region, wherein urbanization has consumed vast acreage of land adjacent to the city proper and has pushed the rural/urban fringe farther and farther from the original Atlanta urban core. An enormous transition of land from forest to urban land covers/land uses has occurred in the last 25 years within the region. For example, analyses of Landsat satellite data between 1973 and 1992 show a decline in forest land of over 18%, while there have been increases of 188% for high density urban and 58% for single family residential land

Figure 3. Small-scale land cover classification places planned development in a larger synoptic context.

cover/land use. The decrease in forest land translates into an average loss of 55 acres of trees per day between 1973 and 1992.

Remote sensing has allowed for the synoptic observation and analyses of urban growth, but this has been at a relatively coarse level (e.g., > 30m) via satellite platforms. With the advent of current or soon to be launched satellite-based remote sensing instruments that provide spatial resolutions of < 10m, it is now possible to obtain a much clearer picture of the environmental impacts of urban growth and highway improvement/development at landscape scales. Moreover, anticipated hyperspectral sensors will provide increased radiometric resolutions that can be used to potentially further the analyses of the state of environmental conditions, and how urban sprawl and associated highway development perturb these conditions.

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The NCRST-E air quality analysis project is being conducted by the Center for Advanced Infrastructure Technology (CAIT) at the University of Mississippi, a consortium partner. The project is focused on remote sensing tunable laser measurements of air pollutants and air quality impact of transportation

Transportation, Air Quality, and Remote Sensing

Laser Measurements of Air Pollutants Related to Highway Traffic in Mississippi – Oxford and Tupelo

systems, which significantly affect the quality of life. The primary product of this project is a state-of-the-art protocol for air quality analysis using remote sensing laser measurements of significant air pollutants related to traffic and transportation infrastructure.

To enforce 1990 amendments to the Clean Air Act, the Environmental Protection Agency (EPA) has developed the Air Quality Index (AQI) considering 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). Key sources of air pollutants are: point and area sources, mobile sources (vehicular traffic, railroad, and non-road engines), aviation, fires, and natural emitters such as Nitrogen Dioxide formation by lightning and biogenic emission of VOC. Air pollution contributions from vehicle emissions — particularly volatile organic compounds (VOC) or Hydrocarbons, PM, CO, and NO_x — result from fuel combustion, fuel evaporation, and refueling losses. Vehicles are becoming more efficient and cleaner, however, vehicle-miles traveled tripled over the last 40 years.

Figure 1. Smog from NO_2 and O_3 pollution.

Ground-level tropospheric Ozone, a major air pollutant, is formed by a photochemical reaction involving VOC, Nitrogen Dioxide (NO_2), and sunlight. Tropospheric Ozone contributes to smog, is toxic, and negatively affects health (Figure 1). Ozone and smog created by NO_2 are particularly high during hot summer days, especially in urban and suburban areas where paved surfaces and constructed roofs cause up to 20 to 30 degree higher temperatures. Traffic gridlocks also result in more Ozone pollution. Despite considerable regulatory and pollution control efforts over the last three decades, high Ozone concentrations in urban, suburban, and rural areas continue to be a major environmental and health concern. Numerous cities and urban areas are listed as nonattainment areas for Ozone.

Differential Absorption LIDAR (DIAL) has been used successfully to monitor atmospheric pollutants, such as O_3, NO_2, Hydrocarbons, SO_2, and Mercury vapors. LIDAR uses laser pulses to transmit and receive electromagnetic radiation. Non-invasive remote sensing DIAL operates on the principle that the absorption of light by the atmosphere and air pollutants varies at different wavelengths. 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. DIAL remote sensing technology has been used for mapping air pollutants using aircraft, vehicles, and building tops.

Real-time in situ remote sensing spectroscopic DIAL technology allows measurements of NO_2 and O_3 air pollutants as they naturally exist in the atmosphere over long pathlengths of several hundred meters. 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 laboratory analysis.

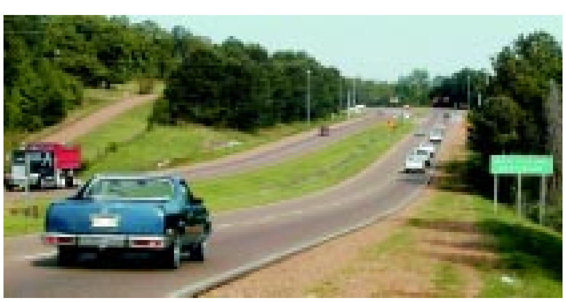

Figure 2. Oxford DIAL test site.

In the first part of Year 2, the DIAL measurements were carried out by tunable DIAL equipment in the first pilot air quality study in Oxford, Mississippi. The test site is adjacent to MS Highway 6 West in Oxford, Mississippi (Figure 2). The airborne XeCl excimer dye laser equipment setup was modified, and a single laser system was adapted as a truck mounted unit for horizontal measurements by Skyborne, Inc. Nitrogen Dioxide (NO_2), a major precursor of Ozone, was successfully measured by tuning the laser between 447.85 nm on-resonance wavelength and 450.00 nm off-resonance wavelength. Figure 3 shows a real-time LIDAR signal in the NO_2 band. The NO_2 absorption band lies in the visible part of the spectrum. It absorbs the blue color of sky, resulting in brown colored smog, as shown in Figure 1 and seen in Figure 4 through a calibration cell of NO_2.

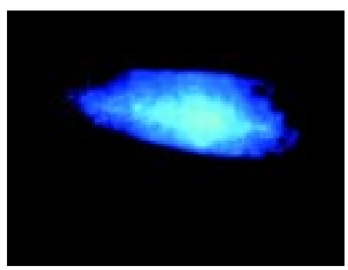

Figure 3. Real-time LIDAR signal.

Traffic data were collected on the test site as part of the on-going City of Oxford's Intelligent Transportation System (ITS) study. Airborne LIDAR and color aerial photo missions developed a comprehensive digital terrain model and GIS of the Oxford area. Wind and other weather data were collected from the nearby NOAA SURFRAD weather station in Batesville. The DIAL results showed nearly 25 times more NO_2 concentration at 10 a.m. (daytime) compared to the measurement at 11 p.m. (nighttime) when traffic was minimal. Higher NO_2 concentration is also associated with higher air temperature in the daytime measurement. These results are greater than 30 ppb which is generally assumed for natural background level of NO2 in rural areas.

Figure 4. NO_2 Calibration cell.

This study indicates that a good air quality simulation model should include traffic volume and air temperature variables. Tupelo is another test site with both a higher population and traffic volume. The study also includes the accelerated highway test track site of the National Center for Asphalt Technology (NCAT) at Auburn University. Other cooperative agencies involved in this study are the City of Oxford, Mississippi Department of Environmental Quality (DEQ), the City of Tupelo, and NCAT at Auburn University.

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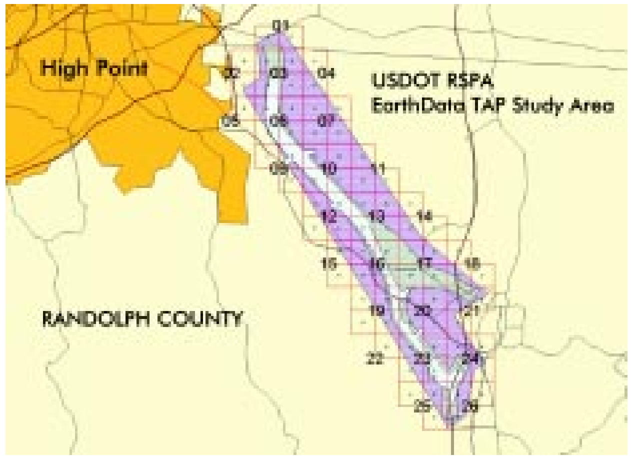

Figure 1. Location of the US DOT RSPA Earthdata TAP study showing the study area near High Point in Randolph County, North Carolina.

Remote Sensing and Geospatial Applications for Wetland Mapping and Assessment for Randolph County, NC

High-resolution hyperspectral imagery and high resolution LIDAR data were collected for an area in Randolph County, North Carolina. The data were gathered by EarthData Technologies, a Technology Application Partner (TAP), with additional funding and support from the North Carolina Department of Transportation (NC DOT). The study area was between Asheboro and High Point, North Carolina in the Deep River watershed. NCRST-E partnered with EarthData and developed data fusion techniques, data stratification techniques, contextual analysis methodologies, and an algorithm for assessing the likelihood of wetlands occurrence.

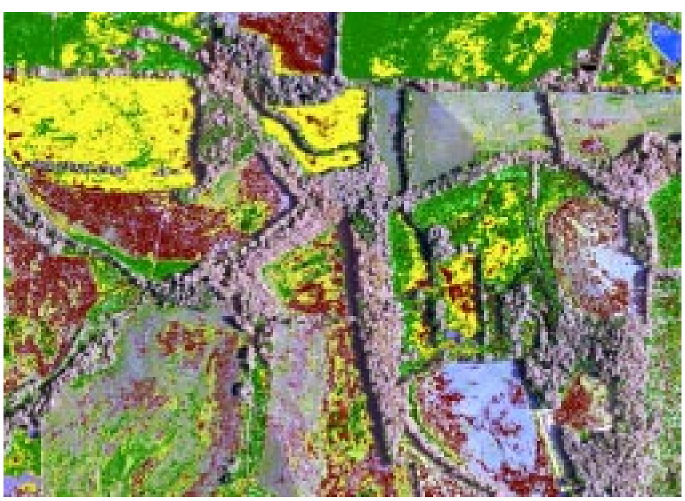

Figure 2. Hyperspectral image data, elevation information, and classification results are fused to show the texture and context of vegetation on the landscape.

High-resolution hyperspectral imagery can be used to identify individual plant species, while high-resolution elevation data offer improved understanding of the topography and hydrology of the area. Digital soils data from U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS) county soil surveys (SSURGO datasets) were used to supplement the enhanced image and elevation data, providing the ability to assess soils, vegetation, and hydrology.

Fusing the collateral soils and hydrology information with the classified results from the

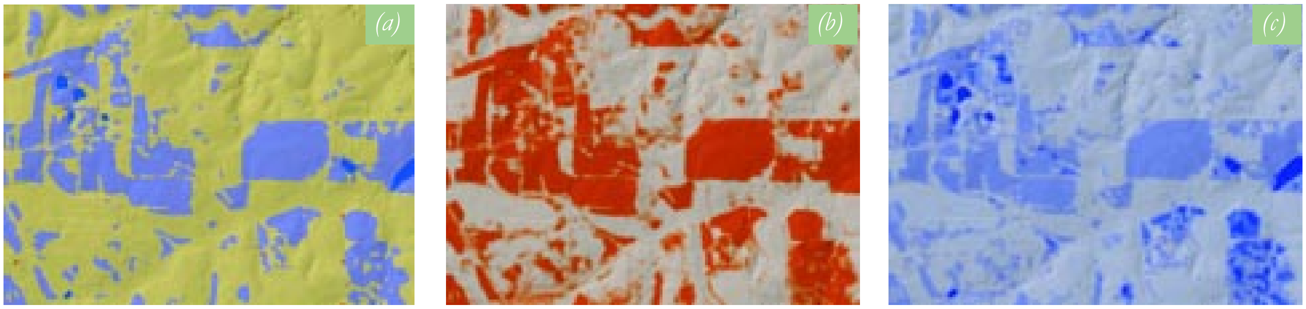

Figure 3. Hyperspectral data and classified results may be stratified to reduce data complexity and clarify results for further analyses that show (a) most significant components of neighboring areas, (b) the weighted sum of components, and (c) the combined dominants present.

hyperspectral image data enabled the images to be viewed in the context of the landscape. However, the context provided by the image data does not sufficiently show assemblage of vegetation. Analyses of neighboring vegetation, hydrologic setting, and soils type are needed for a preliminary determination of the likelihood of an area being a wetland.

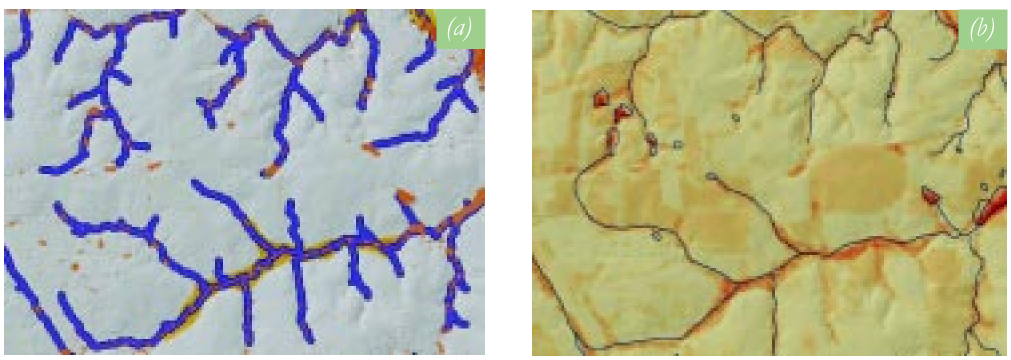

Figure 4. (a) Buffered stream riparian zones, hydric soils, and topographic sinks combined with vegetation information, and (b) ranked to provide a predictive surface that corresponds well with National Wetlands Inventory (NWI) information.

A series of techniques were developed to extract vegetation information for areas adjacent to potential wetland pixels on a classified high-resolution remotely sensed image. They were developed to provide a close surrogate for on-the-ground field biologists' observations — wherein species are counted and an assessment is made. The techniques assess the most significant vegetative component for the neighboring area around each classified image pixel, the weighted sum of components, and the combined dominants present in the neighboring area. Non-vegetation information includes buffered areas around synthetic streams shown in blue, hydrologic depressions in brown, and hydric soils shown in tan. This combination of non-vegetation information products illustrates the spatial overlay of stream and riparian zones, areas likely to pond overland flow, and soils typical of the wetland environment.

The analysis combines the vegetation and non-vegetation information products. National Wetland Inventory information shown in blue overlay the results of the analysis with increasing brown indicating increasing wetland likelihood. The close agreement between the analysis results and the NWI data are evident through inspection of the spatial overlay.

Details of the project can be found by downloading the report from the web at: http://www.ncrste.msstate.edu/publications/ncrste_tg003.pdf.

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Evaluating the Need for Remote Sensing Information to Conduct Environmental Assessment in Transportation for Federal Highway Administration

The National Environmental Policy Act of 1969 (NEPA) (42 USC § 4321) marked the beginning of the environmental review process for all federal actions. The Federal Highway Act of 1970 placed responsibility on the U.S. Department of Transportation (US DOT) Federal Highway Administration (FHWA) to fully consider adverse effects of transportation on various aspects of community. New strategic goals of the FHWA emerged to "protect and enhance communities and the natural environment affected by transportation." In response to the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), FHWA broadened its mission to reflect increasing interest throughout the nation in developing an environmentally sensitive transportation system. The renewed emphasis on the environmental and community impacts of transportation changed the framework of transportation planning.

An assessment was conducted to characterize the framework of laws, regulatory agencies, and procedures within which environmental assessment in transportation is executed, to provide an overview of the information required to conduct an environmental assessment, and to identify areas where remote sensing has the greatest potential as a supplemental source of geospatial information.

Environmental Impact Statements (EISs) are conducted in the context of an overall decision-making process that is inexact and fluid. Despite the fact that EISs are conducted in accordance with Executive Orders, environmental laws, and regulations, the process is laced with subjective components, such as "significant impact," "best available data," and loosely defined accuracy requirements. Although the rationale for EISs is environmental protection, they are not in and of themselves regulatory. The cost to the environment is weighed against the benefits of the proposed project. EISs are simply a source of information on which to base informed decisions.

For the most part, there are no hard and fast rules or requirements in EIS preparation. The laws and regulations tend to address the process, not specific procedures. The courts have determined that the best method does not even have to be used. The information used, however, should have sufficient scientific and analytical substance to provide a basis for comparing alternatives, and should contain sufficient supporting information or results of analyses to establish the reasonableness of the conclusions on impacts. Decisions regarding the adequacy of certain data or methods are up to the dis-

cretion of the engineer overseeing the assessment. The information from remote sensing must be in some way "better" than traditional sources of information before it will be embraced by planners, decision-makers, and other members of the transportation community.

The EIS framework contains significant latitude for the application of remote sensing as a supplemental or alternative source of environmental information associated with transportation development. Of the 25 environmental impact areas the FHWA recommends addressing in an EIS, 13 are good candidates for remote sensing in some capacity. In many cases, current "off-the-shelf" techniques can be utilized directly. In other cases, the assessment requirements dictate using newer data sets for which experience is limited or for which image processing techniques need to be refined or developed. However, these issues do not appear to be insurmountable obstacles.

EIS preparers and stakeholders must be convinced that remote sensing offers "better" data, as it was previously defined, and this in turn can lead to better, more informed decision-making. This puts the onus on those developing remote sensing applications to educate stakeholders about what remote sensing has to offer so that they will consider its application as an additional source of information to meet existing requirements. Remote sensing should be viewed as a supplement to or enhancement of existing information, not as a replacement. The advantages of remote sensing in meeting agency performance criteria should also be presented. Even without improvements in decision making, remote sensing may be a more cost effective approach to assessment in some instances. For small-scale projects, remote sensing may be too costly at this time, but for large-scale projects, remote sensing techniques can offer significant cost savings compared to conventional on-site measurements.

Perhaps the greatest challenge is in obtaining broad utilization and acceptance of remotely sensed imagery. Skepticism, unfamiliarity, cost, capital equipment and human resource needs are just a few of the anticipated impediments that must be addressed before broad utilization and acceptance can be achieved. In some cases these impediments are real and substantial, but in many instances they are fairly trivial. The NCRST-E is appropriately positioned to provide the research, development and outreach services needed to raise remote sensing to the forefront of environmental assessment in transportation. The lessons learned over the last fifteen years with the implementation of GIS and GPS technology in transportation planning and engineering should be applied to remote sensing technology as well. A broad array of demonstration projects are needed, not simply to provide examples of remote sensing capabilities, but to engage the stakeholders in the process, assess the costs and benefits relative to performance indicators, and demonstrate overall the intrinsic value in accepting change.

The full findings of this assessment are documented in a Technical Guide that can be found at *http://www.ncrste.msstate.edu/publications/publications.html*.

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Automating Wetlands Identification to Meet Federal Reporting Requirements for Virginia DOT

This project provides the opportunity to prove the usefulness of integrating multispectral imagery into everyday workflows for the wetland identification process for the Virginia Department of Transportation (VDOT). The approach does not intend to replace wetland delineation methods required by the 1987 Corps of Engineers Wetlands Delineation Manual. Rather, this approach demonstrates 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, the integration of this data with numerous GIS data layers into the enterprise GIS architecture, and the resulting forms creation and data population, the entire complex process has the potential to be streamlined and enhanced. This research will be evaluated by end-user interviews and an assessment of the GIS integration process.

The investigative approach towards streamlining wetlands identification begins with a review of the VDOT process of wetland identification for planned construction projects. Stakeholders in VDOT's Environmental Division have assisted by identifying a planned project that could benefit from this proposal's thesis. Some preliminary planning work has already been completed and will provide a good baseline of comparison of existing processes and potential timesavings through the application of remote sensing technology. A review of the already complete processes as well as an understanding and documentation of the remaining processes will assist in baselining the present process. This baselining will prove invaluable in evaluation of the completed research to see if the automation actually can provide benefits in streamlining the process.

The project that has been identified with the assistance of VDOT's Environmental Division is a relocation and reconstruction of US Route 17 in the City of Chesapeake, VA (project # 6017-131-105). This project already has a draft Environmental Assessment completed. In it, jurisdictional wetlands were delineated using a combination of National Wetland Inventory (NWI) mapping, Soil Survey of Norfolk County, VA, recent aerial photography and field reconnaissance by VDOT and US Army Corps of Engineers personnel. In addition, this area is located in the Dismal Swamp vicinity, an area with many acres of wetlands and high developmental pressure where a construction project could have a large impact upon wetland areas.

The ultimate goal of the research is to provide a "cookbook" approach for the integration of multispectral photography into existing GIS architectures that may prove to be useful to other state DOTs.

"Mpower3/emerge" 3 band multispectral imagery will be acquired for the proposed relocation of US Route 17. The project location will be flown three times: spring, summer and fall 2002. Existing ground truth information will be used to confirm the findings from the imagery.

Wetland vegetation in the study area has been identified in the Draft Environmental Assessment prepared for the Federal Highways Department (VDOT, November 2000) and includes five wetland communities: 1) mixed pine-hardwood forest; 2) recently clear-cut mixed pine-hardwood forest; 3) bottom-

Figure 1. US Route 17 re-alignment, Dismal Swamp.

land hardwood forest; 4) red maple swamp; and 5) farmed wetlands. The range of reflectance values for the signatures of these plant communities must be established for the imagery acquired. Erdas Imagine Sub-pixel Classifier software will be used for this procedure. Unsupervised classification will be performed first. The values will be refined and the supervised classification used to create polygons of potential wetlands sites.

The resulting polygons that will be produced from the Erdas Sub-Pixel Classifier will be brought into ArcInfo and layered with other environmental data, including NWI (National Wetlands Inventory) polygons and NRCS (Natural Resource Conservation Service) SSURGO (Soil Survey Geographic) soils data. SSURGO soils data are geographically referenced ArcInfo coverages showing soil types at a scale of 1:24,000. According to the Draft Environmental Assessment, the wetlands in the study area can be differentiated into two soil types, organic soils and hydric mineral soils. The soils coverage will have to be filtered for these soils and compared to the new sites.

In addition to the NWI SSURGO data, the Soil Survey of Norfolk County, Virginia (USDA-SCS, 1959) paper maps can be used to check results. Although these data are not in digital format, the survey was used by VDOT in the Draft Environmental Assessment and may provide more detailed information about the study area.

The resulting georeferenced spatial data (digital orthophotography, polygons produced from Erdas Sub-Pixel Classifier, NWI polygons, SSURGO polygons) will be loaded into the VDOT Oracle/SDE database, which already contains base data such as roads, jurisdictions, hydrology, rail, USGS Digital Ortho Quarter Quads, and VDOT business data (such as accidents, traffic counts, construction projects).

The GIS data will be served via the VDOT intranet to the Environmental Analyst's desktop browser. The java client allows the end user to redline and create notes that can be incorporated into the other spatial data. As the VDOT network is a statewide intranet connected by Asynchronous Transmission Lines (ATM), the Central Office Environmental Analyst in Richmond can share digital information with the district Environmental Analyst, in this case the Hampton Roads District.

If polygons appear in areas not designated by NWI data or not on SSURGO hydric or organic soils, these areas will be checked on the imagery and by field visits. Also, the Draft Environmental Assessment states that the construction potentially impacts 17.7 acres of wetlands. The area of the new wetland polygons can be determined in ArcInfo and compared to this number. Both of these comparisons can evaluate the results of this proposed procedure.

Output forms will be designed to aid in the development of preliminary permit information that will be necessary in the wetland permitting process. This will be an iterative process that will need to be fine tuned as it evolves. Regular feedback from the Environmental Division will provide the opportunity to evaluate and assess the usefulness and applicability of the database and form information.

Credits: Project Lead:Virginia Department of Transportation GIS Program.
Partners: Virginia Department of Transportation Environmental Division, Vargis LLC, Herndon, VA and Terralogics, Inc, Staunton, VA.

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EarthData International

Airborne Sensor Fusion: A Fast-Track Approach to NEPA Streamlining for North Carolina DOT

In 1997, the U.S. Army Corps of Engineers (USACE), the Federal Highway Administration (FHWA) and the North Carolina Department of Transportation (NCDOT) signed into action the Integration Process for Surface Transportation Projects in North Carolina Merger Agreement. This agreement describes a team approach to integrating NEPA and Section 404 of the Clean Water Act permitting during transportation project planning, design and implementation. Goals of the merger agreement are to better serve the public, expedite construction, complete projects on budget and schedule and to protect and enhance water quality.

The North Carolina merger agreement mandates formal concurrence by all interested agencies in each of four project stages, from initial project planning, development of alternative corridors, selection of the "least environmentally damaging practicable alternative" (LEDPA) and finally, environmental impact minimization in the selected corridor. Selection of the LEDPA corridor can frequently take years while various interest groups debate effects on both the physical and cultural environment. In support of these debates, the state department of transportation is often asked to provide detailed engineering design plans for alternatives in order to address the concerns of all parties.

Today, most state DOTs use conventional aerial photography, labor-intensive photogrammetric mapping and field surveying to develop planning maps and engineering designs. Recent advances in airborne remote sensing offer significant streamlining of the same mapping and engineering tasks, saving valuable time, reducing project costs and providing more accurate content than previously available using conventional means. EarthData International and ITRES Research Ltd, in partnership with the North Carolina Department of Transportation, demonstrated innovative uses of airborne remote sensing to streamline environmental permitting under the NC merger agreement. Low-altitude airborne data were needed to meet the high spatial accuracies and resolutions required for engineering tasks that are often part of the review and assessment process. These technologies were applied to an existing transportation corridor study in North Carolina to compare the productivity of new techniques to old, and to instill confidence among the NCDOT photogrammetrists and engineers that the new data indeed meet their stringent accuracy requirements.

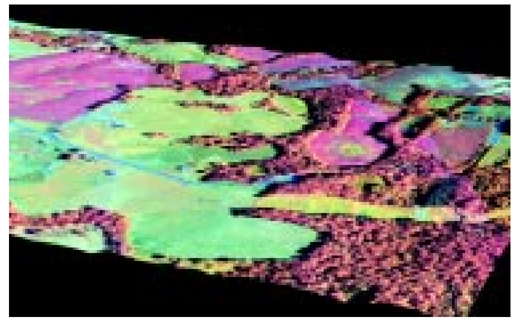

Figure 1. Hyperspectral image data fused with LIDAR elevations for enhanced ability to assess and visualize environmental conditions.

EarthData International collected aerial photography using airborne GPS and inertial measurement (IMU) control. The exterior orientation of each photo was directly measured, the aerotriangulation step required in conventional photogrammetric mapping was eliminated, thereby reducing labor costs and saving time. While airborne GPS and IMU have been used in some commercial mapping applications, the EarthData/NCDOT project was one of the first to demonstrate that these technologies were appropriate for large-scale engineering. Airborne GPS and IMU results passed the accuracy requirements set forth by NCDOT for 1″=100′ and 1″=200′ mapping and orthophotography, which are standard data products for preliminary engineering design. Based on these encouraging results, NCDOT has now modified the technical scope of photogrammetric mapping contracts to include airborne GPS and IMU with aerial photography acquisition.

In addition to geo-referenced and orthorectified aerial photography, one of the most valuable mapping products used in transportation planning and design is a 3-dimensional model of the terrain. Terrain models form the basis for geometric design of a roadway or rail facility. They are also used to analyze hydrology and drainage, calculate cut-and-fill volumes and determine construction costs. Finally, 3-dimensional terrain data and aerial imagery can be merged to create models, simulations and visualizations of a proposed transportation facility embedded in the existing natural environment.

In today's DOTs, terrain models are created by labor-intensive photogrammetric digitizing of stereo aerial photography. LIDAR (Light Detection and Ranging), a laser-based topographic mapping technology, has recently emerged as an extremely rapid and cost-effective alternative to photogrammetry, but industry development of standards and guidelines, suitable for implementation at a state DOT, have not kept pace with the technology. In an effort to overcome this barrier, EarthData acquired LIDAR data over the entire project study area. NCDOT validated the accuracy of the LIDAR-derived terrain models using extensive field surveys. The LIDAR terrain model was demonstrated to meet the DOT's accuracy criteria for preliminary engineering design. As a result, NCDOT is accelerating plans to include LIDAR in the scope of upcoming transportation corridor projects.

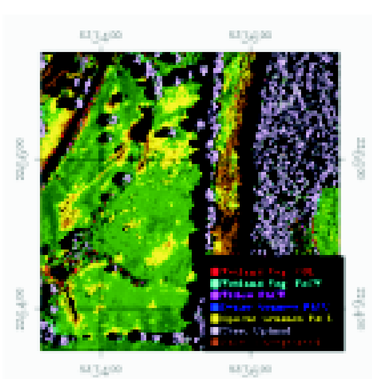

Figure 2. Hyperspectral image data classified to assess the vegetative land cover.

In North Carolina, identification of jurisdiction wetlands in a proposed transportation corridor is one of the most costly and time-consuming data requirements in an EIS. Present methodologies for identifying wetlands rely exclusively on field surveys. Airborne remote sensing provides an important screening tool to assist wetlands biologists in the evaluation of alternative corridors and the effective planning of jurisdictional wetlands surveys required by law.

ITRES Research Ltd. acquired hyperspectral imagery at 60 cm GSD and 1 meter GSD over the project study area. Using a small number of field samples, image analysts targeted and identified vegetative species that are known to indicate potential wetlands. Consulting with MSU, EarthData International and ITRES were then able to combine these vegetative wetland indicators with LIDAR-derived hydrology and digital hydric soils to produce wetlands probability maps. The maps were compared against field surveys performed by NCDOT following U.S. Corps of Engineers specifications for wetlands delineation. The data fusion techniques described above were used to correctly identify wetlands as small as ¼ acre, the minimum size unit currently mapped using field surveys.

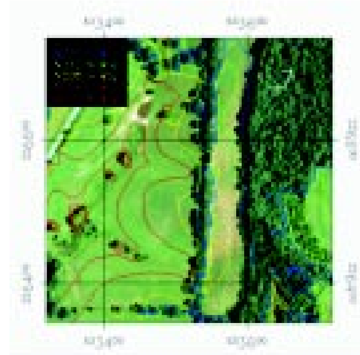

Figure 3. The LIDAR terrain model used for topographic and hydrologic assessment.

Using conventional methods, a DOT can often not afford, or be able to wait for, highly accurate geographic and topographic data over all potential corridors under consideration in an EIS. Airborne remote sensing technologies provide the means to collect better data, faster and at a lower cost. As these demonstrated technologies are validated and adopted into standard practice, DOTs can save time and money on most of their preliminary planning and engineering design activities. This in turn streamlines the NEPA permitting process by producing accurate results more quickly and allowing more potential corridors to be examined effectively within existing project budgets.

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Demonstrating Remote Sensing Solutions for Environmental Analysis of the Washington State I-405 Corridor

One of the most expensive and time-consuming aspects of early transportation project planning is the selection and environmental assessment of potential routes or corridors. The environmental review processes mandated under the National Environmental Policy Act (NEPA) generally require extensive data collection on potentially affected environmental resources for several alternative proposals. In order to be credible, Environmental Impact Statements (EISs) generated to meet National Environmental Policy Act requirements should be based on good quality data and a clear demonstration that appropriate alternatives have been considered and evaluated in an objective fashion. Remote sensing data can contribute to improving this environmental review process by providing a credible baseline of information for evaluating alternatives early in the process and eliminating unnecessary and costly detailed analysis.

Figure 1. The primary study area extends one to three miles on either side of I-405, between SeaTac and Lynnwood (Landsat7 base).

Transportation system improvements are desperately needed in Washington State's Puget Sound metropolitan area. The highly urbanized Interstate 405 corridor is one of several programmatic environmental analyses for transportation improvements either in-process or planned for the metropolitan area. Unfortunately, transportation planning and the National Environmental Policy Act (NEPA) process for major projects have become long and costly — not only in the State of Washington but nationwide — and have delayed the delivery of transportation improvements to the point where considerable time and money have been lost. By comparing the cost and quality of results obtained from traditional data collection methods with those developed here, this project aims to demonstrate an approach that uses remote sensing technologies to streamline environmental analysis in the transportation planning process.

The project consists of six major tasks: 1) Field study in two stages — collect ground-truth data prior to image analysis, and then evaluate the image-analysis results against the real-world. 2) Compile and evaluate available image data and fuse these data to create the best possible resource for image data analysis. 3) Characterize land use and land

Figure 2. High-resolution color orthophoto of roadside wetland.

cover (LULC) in the region. 4) Integrate the LULC characterization from the previous task, with GIS and other data, to provide LULC and transportation images, and related analysis. 5) Develop estimates and compare the cost and quality of information developed with conventional methods with those developed in this project. 6) Document the procedures, analysis, and findings to institute technology transfer into transportation organizations.

The project strategy is not to lock into a specific remote sensing technology, but to adopt an approach that combines different technologies in order to achieve synergistic advantages. Image data available for this project include Landsat-7 and IKONOS multi-spectral scenes, black and white orthophotos produced by the Washington State Department of Natural Resources, and high-resolution color orthophotos produced by the Washington State Department of Transportation. Methods are being developed to fuse these technologies to take advantage of their different characteristics and achieve synergistic results.

The multi-spectral imagery provided by Landsat-7 contain spectral signatures of many different features, which can be exploited to obtain information on land use and land cover classes — information that is important for environmental analysis and the transportation planning process. Using IKONOS imagery, road pavement, edge lines, and central stripes can be accurately mapped. Bridges, parking lots, and even vehicles on or along the roads can be identified. Environmental conditions and transportation impacts such as urban growth, increased area covered by impervious surfaces, or habitat fragmentation can now be evaluated with much better accuracy. Available GIS data layers such as transportation networks, demographic data, and topographic map data along I-405 have also been collected. Imagery and vector data are being integrated to form a source database for analysis. To handle data integration, the project will use two major commercial software products: the IMAGINE image processing system and ARC/INFO GIS.

Project products will include: 1) A spatial database of raw image data from a variety of remote sensing sources, and derived and interpreted information in GIS format including land use and land cover information. 2) Software procedures accessing multiple data sources to derive land use and land cover information and to identify and delineate areas where proposed transportation development is likely to cause environmental impacts. 3) Cost-benefit analysis of study methods and a comparison to costs of conventional practices, including qualitative comparison of content, accuracy and timeliness. 4) Guidelines for use of these methods and techniques by other transportation agencies.

Credits: Principal Investigator:
Washington State Department of Transportation.
Partners: Oak Ridge National Laboratory, Space Imaging, Erdas, U.S. Environmental Protection Agency, Wisconson Department of Transportation.

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Regional Databases for Transportation Corridor Planning in the Mississippi Gulf Coast Corridor

Transportation planning requires extensive amounts of geographic and demographic information. It is therefore logical and necessary that this information be collected and stored within a comprehensive database for ease of access by transportation planners. Much of the importance of this information is based upon the location of features within a given transportation corridor. Based on this fact, development of a geographic information system (GIS) database is a valuable tool for the transportation planner. Once the data have been collected and compiled, it is important that the information be made readily available to users and stakeholders. Sharing this information across the internet provides an effective method for providing quality information to users.

Geographic information systems are a tool commonly used by city and local planners for transportation planning. However, it is typically expensive and time consuming to create these databases, which are often limited in scope and spatial coverage. In addition, many commonly available data sources are old or do not contain sufficient detail or precision to meet the needs of today's transportation planners. The advent of commercially available remotely sensed imagery provides a means of evaluating and updating geographic data for use in transportation planning. In addition, remotely sensed imagery often provides a means for collecting data about locations that may be difficult to collect using other methods.

The purpose of this project was to demonstrate the value of using remotely sensed imagery to update existing geographic data sources and to create a comprehensive database of geographic information including natural, social and demographic environmental features. The value of this information collected in a single location is the ability to rapidly assess potential environmental impacts for potential transportation alignment alternatives.

Remotely sensed imagery provides a means for collecting extensive information over large areas for evaluating and updating geographic data including land use and demographics. Use of remotely sensed imagery over time can also allow for analysis of changes that can be used to

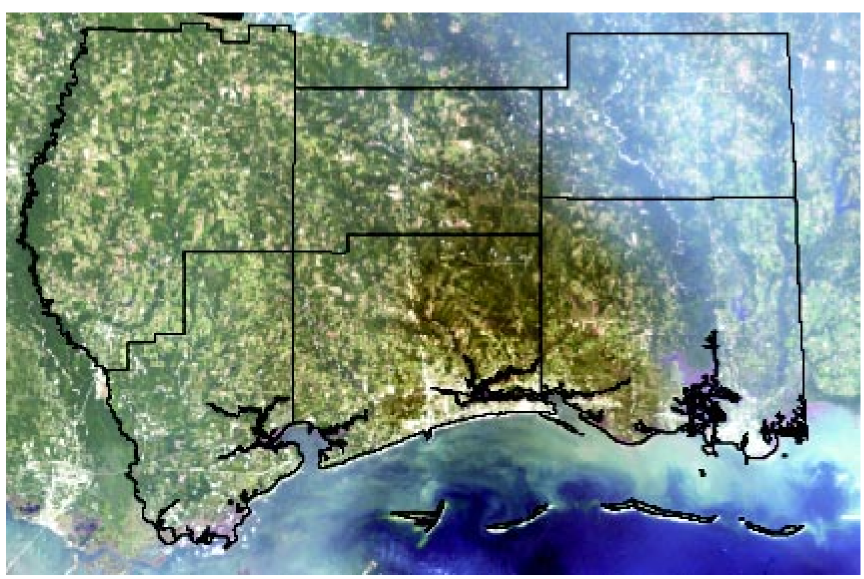

Figure 1. Landsat 7 mosaic showing the six southern county database extent.

predict future land use and urban growth.

The geographic database developed for this project covered a six county area in southeast Mississippi and was based upon a database developed for the Gulf Regional Planning Commission (GRPC) during the summer of 2000. This database used largely existing data layers from the Mississippi Automated Resource Information System (MARIS), a geographic data clearinghouse located in Mississippi. The data consisted of ArcView shape files and remotely sensed imagery from the Landsat-7 satellite.

The remotely sensed imagery was used to update the shape files. Change detection analyses were conducted to determine where changes had occurred during the past ten years. These areas were then compared to the existing shape file data layers. Physical features that were evident in the imagery but missing in the shape files were added. Additionally, new vector layers were created to show changes in land use practices. The completed database was then compiled onto an Internet Map Server (IMS) to allow for sharing the data across the Internet.

Other project functions included evaluation of digital elevation model (DEM) data sources including data from the USGS, photogrammetric analyses and from the Star-3i system. Each data source was compared against ground truth data collected using global positioning systems (GPS). The study found that for studies over large areas, DEM data provided by the USGS are a cheap and effective data source. While the resolution of the imagery is relatively coarse, it compares favorably with ground truth data.

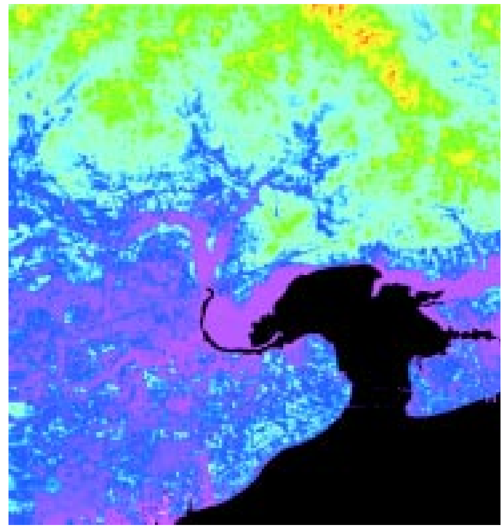

Figure 2. Digital Elevation Model (DEM) of Bay St. Louis and surrounding area.

The final aspect of the project consists of developing a transportation planning tool that will allow the user to conduct some basic analysis of potential alignment impacts. Using ESRI ArcView software primarily, the tool will read the data from the geographic database and allow for visual displays of the various data layers. Users will be able to load CADD files or draw basic alignments, specify right-of-way requirements and print the impacts into a matrix. The user will then be able to print a strip map of the alignment at a specified scale for use in field verification. Use of this tool in combination with a regional database will allow planners to quickly evaluate alignment alternatives and compare environmental impacts. It will also allow the user to make changes and evaluate them rapidly without having to conduct additional field investigations.

Project Contributors:
Gulf Regional Planning Commission,Southern Rapid Rail Transit Commission, Mississippi State University, Engineering Research Center.

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The **NCRST-Infrastructure** (NCRST-I) Consortium focuses on how remote sensing and spatial information systems can improve current methods for planning, constructing, and maintaining the nation's transportation infrastructure. To be useful, new methods based on these technologies must significantly improve the ability of transportation agencies to carry out their tasks, and the consortium has taken a broad view of the role of technology, arguing that new methods are useful only if they can be delivered to the agency's staff in a form that is intuitively straightforward to learn and easy to use. For example, it is not sufficient that data be available somewhere, in some form; data must be available at the desktop, already compatible with existing desktop systems, and well documented. The consortium has developed a range of technologies that implement this vision, as described in the following pages.

The path from satellite or other data acquisition system to the user's desktop is often complex, and frustratingly slow. Data are pre-processed, interpreted, and reformatted, and then stored in digital warehouses, and made available through web sites with various forms of search capability. Once a user has found a candidate data set, it must be evaluated for quality and suitability, downloaded, catalogued in the user's own archive, integrated with other data sets from other sources, and finally put to use. NCRST-I is interested in all possible ways of simplifying and speeding this complex process.

For example, the consortium partner Orbital Imaging Corporation (ORBIMAGE) is experimenting with new tools that allow images stored in remote archives to be integrated directly into Bentley's Microstation at the user's desktop. Full details of this "instant imagery" demonstration are included below. With these tools, imagery can be integrated from remote sources in seconds, and displayed in a form that is fully compatible with other data sets.

Another part of this effort by NCRST-I, to provide broadly based solutions to the problems associated with using the products of remote sensing, is its partnership with Environmental Systems Research Institute (ESRI) to develop a specialized data model for transportation applications of spatial information technologies. UNETRANS is an object-oriented model that is designed to incorporate all the classes of objects regarded as essential by transportation-agency users of geographic information systems (GIS). UNETRANS has been developed in a two-year program of consultation with the transportation community, both nationally and internationally. The result is a data model that has immediate appeal to transportation professionals, because it contains all of the basic and essential objects and classes, as well as relationships between classes. Using UNETRANS, it is easy to store infrastructure data in a framework that already contains all of the necessary attributes and relationships, and links to standard GIS operations, including query and basic analysis (Figure 1).

The consortium is experimenting with many different sensors, including LiDAR for high-accuracy measurements of elevation and structural form; AVIRIS and other hyperspectral sensors; high-resolution imaging systems; and GPS. Many methods of analysis and modeling are under investigation, including simulation, basic GIS techniques, and optimization. Investigation of current and future sensors is an important task of the consortium, and research is currently under way to identify new sensor designs particularly adapted to the needs of transportation infrastructure. NCRST-I sees its role as operating in two directions: in research that improves the availability and usefulness of existing remote sensing instruments and spatial information technologies; and in identifying, documenting, and advancing the needs of the transportation community for improved and better-adapted instruments and technologies.

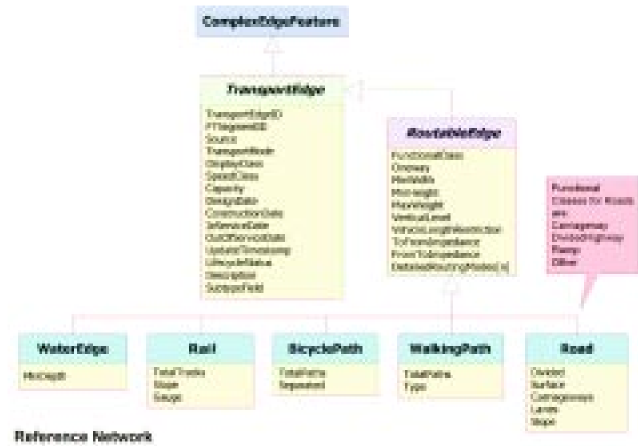

Figure 1: Part of the UNETRANS data model.

Besides the traditional tasks of inventory and maintenance, NCRST-I is devoting increasing attention to the concept of critical infrastructure and its protection (CIP). The same remote sensing techniques that are being explored to support traditional infrastructure management tasks are also powerful ways of addressing vulnerability. The consortium is working on projects that use data derived from remote sensing to plan and assess evacuation strategies; to find cost-effective ways to improve the coverage of wireless communication and monitoring along the transportation network; to identify critical nodes and their vulnerabilities; and to evaluate the risks associated with elements of transportation infrastructure. These activities are expected to grow in importance in the coming year, with a series of events bringing together local transportation and emergency response authorities, academics and the private sector.

Use of LIDAR to Improve the Highway Location Planning and Design Process for Iowa DOT

To reduce the time required to plan and design highway projects, highway agencies have begun to streamline processes. In order to meet the extensive data requirements for environmental assessment and final design, some agencies have chosen to collect and process more terrain data and imagery products than they will ultimately need, to be able to respond rapidly to changing location decisions. While its facilitates a smoother, faster planning process, the additional data collection and processing is expensive and time consuming. For example, a highway bypass study may require as much as $500,000 and 24 months of photogrammetric processing (Figure 1).

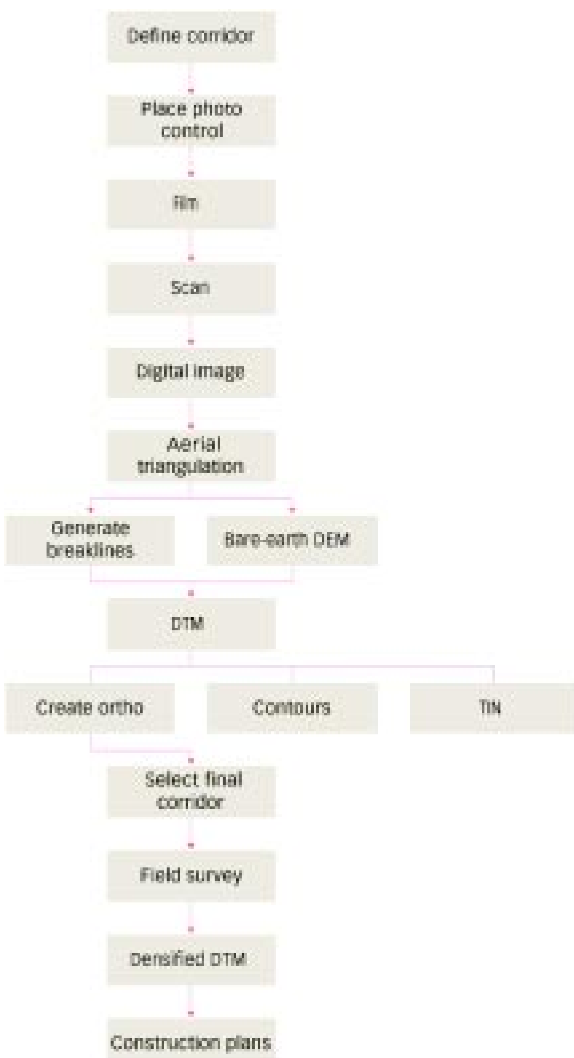

Figure 1. Photogrammetric process.

The existing process requires early collection and processing of data to support final design. However, only the final design stages of project development may require the accuracies provided by conventional photogrammetric processing. The Iowa DOT proposed that advanced methods of surface mapping (LIDAR) and digital photography may be used for preliminary planning and location issues, limiting expensive and time consuming photogrammetric work to the final alignment corridor. Further, inherent inflexibilities of aerial photography (leaf-off, high sun angle conditions) requiring spring flying, was not always convenient for project task sequencing.

If LIDAR developed terrain products and digital imagery were sufficient for planning stages,

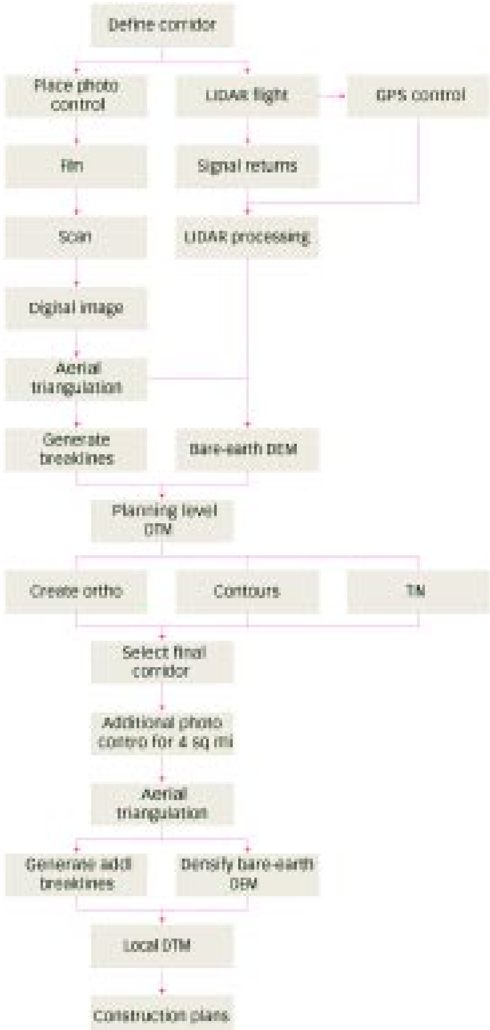

Figure 2. LIDAR supplementing photogrammetry.

	Lidar vs. Ph	USGS vs Ph	USGS vs. Ph
No. of Pts.	290	394	46
Horiz tol.	0.1	0.1	0.6
Mean Z diff	0.75	1.85	1.26
RMSE	0.87	0.89	1.26
NSSDA	1.70	1.74	2.47

Table 1. Preliminary results.

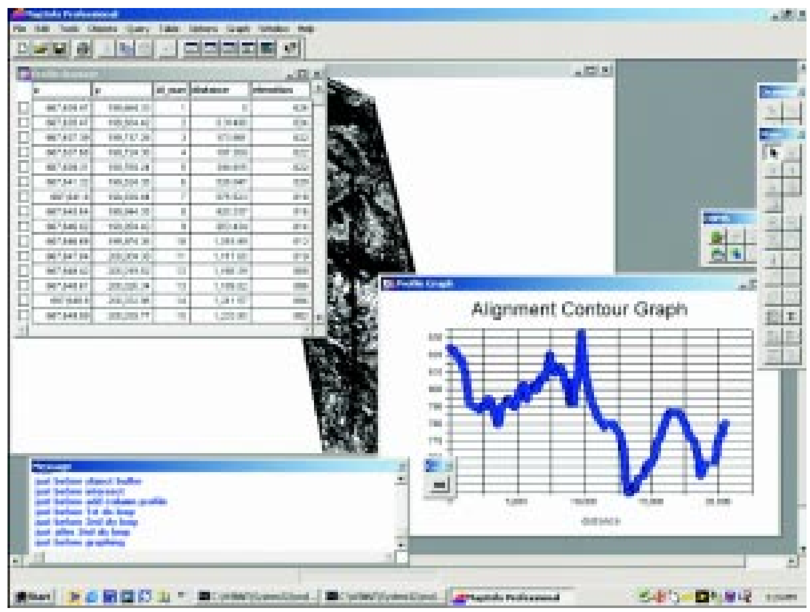

Figure 3. Earthwork calculations.

products could be delivered to planners and designers faster at lower cost. Once final alignment decisions were made, photogrammetric control and processing could be limited to an area perhaps one fifth or smaller than the original location corridor. This scale of photogrammetric work could be completed in less time at much reduced cost. See Figure 2 for a representation of the LIDAR enabled process.

Early estimates indicate a possible time savings of 18 months and cost reduction of $300,000.

In order for these savings to be realized, engineers and planners must be able to use the products, and resulting designs must be of sufficient accuracy. The project considered two principal aspects: (1) how the process to produce terrain and imagery products changes, e.g., how LIDAR and digital photography could be introduced into the process (Figures 1 and 2), and (2) how the substitution of LIDAR for photogrammetry affects accuracy and applicability of resulting terrain and image products. Specifically, the project tests the accuracy of LIDAR elevation estimates for various surface types (road, ditch, crop areas, forest cover, etc. — Table 1), and gross estimates of earthwork differences resulting from the use of photogrammetric and LIDAR terrain models (Figure 3).

Credit: Zach Hans

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Transportation Centerlines:
Case Studies from California and Iowa

Road and rail centerlines are foundation data bases for location referencing and infrastructure asset management. New mission-critical applications in emergency response and Intelligent Transportation Systems (ITS) rely on location-awareness, and require accurate feature alignment data. Integration of other data layers with transportation centerlines multiplies the value of the data, allowing roads to be studied in the context of population concentrations, strategic facilities such as nuclear plants, and environmental regions such as flood zones and fire-risk areas. Some jurisdictions have invested in accurate centerline data and their upkeep; others are not able to bear the costs.

Accuracy requirements for centerlines are application-dependent, and range from centimeters to tens of meters. There are several technologies available for centerline survey, each suited to a data quality domain and price point. The consortium's approach is to push the frontiers of the science as well as to document and to test feasible practices, to inform users of available options.

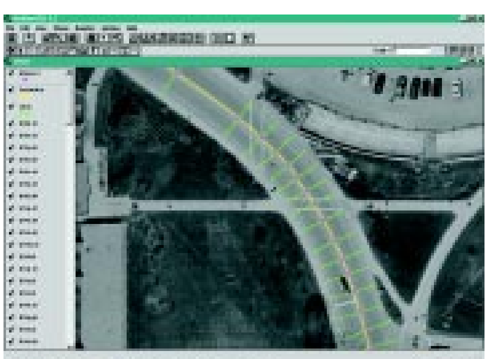

Figure 1. Centerline geometry extracted from aerial photograph.

Centerlines from large scale photography. To achieve ±0.5% linear accuracy for compatibility with distance measuring instruments (DMIs), the preferred centerline extraction method has traditionally been photogrammetry. Researchers at Iowa State University studied the accuracy with which various resolutions of photography, from 5 cm to 1 m, could be interpreted to derive unambiguous anchor points for defining linear sections. They also derived centerlines by interpolating mid-points between curbs in high-resolution photos (Figure 1), and compared those results against DMI lengths. This work guides agencies in finding the least expensive photography to suit their accuracy requirements.

Centerlines from GPS. At Santa Barbara and Iowa State, the GPS solution was explored. GPS can be used by a single vehicle on a dedicated survey; alternately several vehicles on regular duty (e.g. police patrols) may be outfitted with low-cost ($150) units, and their readings pooled. In the latter case, in addition to carriageway geometry, stop signs and signals are detectable. Geometric curve fitting is applied to compensate for GPS error and under-sampling on curves, to produce centerlines compatible with linear referencing. On the most sinuous mountain roads, 99% correspondence between GPS and DMI length is being achieved.

Hyperspectral remote sensing. The above solutions are appropriate at the 1:5000 to 1:1000 scale. Remote sensing is

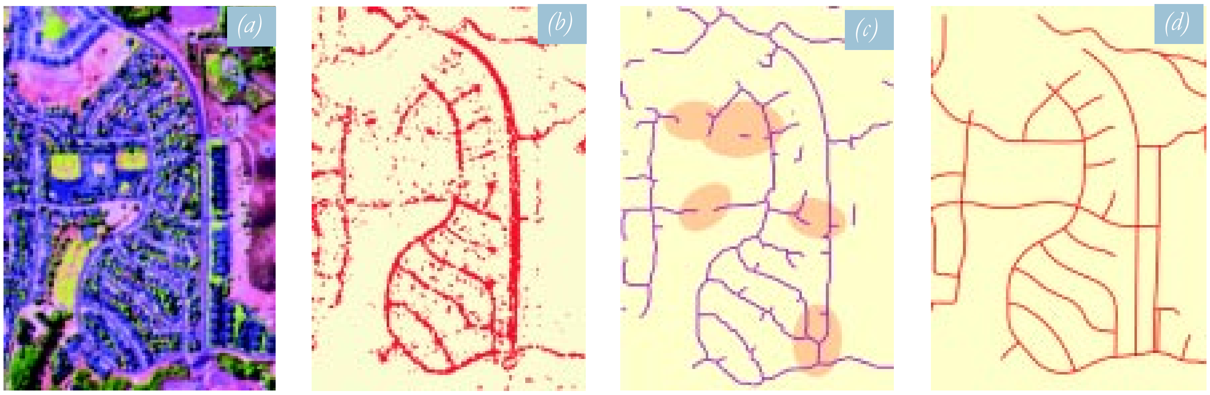

Figure 2. (a) Hyperspectral image. (b) Pavement classified with reference to spectral library. (c) Vectorized centerlines. (d) Reference centerline map.

better suited to mapping at 1:10,000 or smaller scales. The greatest methodological challenge is in urban areas because of the variety of manmade materials. Hyperspectral sensors are best at distinguishing between surface types. Field data were gathered off a number of streets in Santa Barbara using a hand-held spectrometer, creating a library of about 5000 urban spectra — asphalt and concrete road textures, roof shingles and terraces. AVIRIS 4 m imagery (Figure 2a) was compared against the library, and a preliminary map of urban materials derived (Figure 2b). Point and area features, often rooftops, were filtered out, and the output was vectorized using two commercial products, WinTopo™ and Feature Analyst™. The result (Figure 2c), compared with an accurate centerline map (Figure 2d) shows errors of omission and commission, highlighted in Figure 2c (other discrepancies are attributable to the data being from different dates). Clearly, even with hyperspectral imagery, there remains a role for manual supervision.

With this in mind, the techniques and spectral library developed to address the challenging urban problem will work well in rural areas, where the mixes of materials are simpler, and there is a greater need to improve the quality of road centerlines, in terms of both presence/absence and alignment. From what we now know about pavement signatures, even multispectral data are likely to be sufficient in rural areas. The generalization of hyperspectral signatures to multispectral analysis is explored in the next project.

An auxiliary benefit of the research is the ability of hyperspectral data to distinguish construction materials. Concrete signatures are distinct from asphalt, and the age of asphalt can be estimated. However, the more pertinent physical attributes of surface condition — rutting and cracking — cannot be determined from spectral signatures.

In the future, intelligent vehicles equipped with GPS and inertial measurement units will incidentally gather a wealth of alignment and condition data, at least for well traveled roads. The problem areas are remote roads, in the U.S. and abroad. For the present the most practical and cost effective survey methods continue to be larger scale photography, partially automated image processing, and GPS. For rural roads, multispectral remote sensing offers a possible solution.

For a more thorough treatment of this subject, visit the Research and Resources sections of the consortium web site.

Credits: Iowa State University: Reg Souleyrette, Shauna Hallmark, David Veneziano. University of California Santa Barbara: Dar Roberts, Meg Gardner, Qin Zhang, Francisco Iovino, Chris Funk.

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Determining Optimal Sensor Wavelengths for Urban Land Cover and Infrastructure Mapping – A Study of Santa Barbara

A major problem in urban area remote sensing is the complexity of the urban environment at fine spatial scales, which results in very complex and indistinct spectral responses. Recent sensor development including high spatial resolution spaceborne systems like IKONOS (with 1-meter panchromatic and 4-meter multispectral resolution) and hyperspectral sensors like AVIRIS, have the potential for improved and more detailed mapping of urban land cover and land use. Though spaceborne sensors are limited in their spectral resolution, hyperspectral data provide versatile spectral information that potentially can discriminate urban materials at a greater level of detail.

One of the goals of NCRST-I is to determine the best remote sensor characteristics for distinguishing transportation infrastructure from other urban materials. This study aims to contribute to a better understanding of spectral urban surface properties and to analyze the potential for accurate mapping from current remote sensing systems. To accomplish this, three sensors were tested for urban land cover mapping including hyperspectral AVIRIS and multispectral IKONOS and LANDSAT Thematic Mapper (TM) data. To avoid uncertainties in the analysis due to image differences, 4-meter AVIRIS data were used to simulate 4-meter IKONOS and TM. This investigation includes the analysis of urban land cover spectra, measures of spectral separability and image classification techniques to evaluate the performance of specific sensor configurations for detailed mapping of urban land cover types over a test area in Santa Barbara, CA.

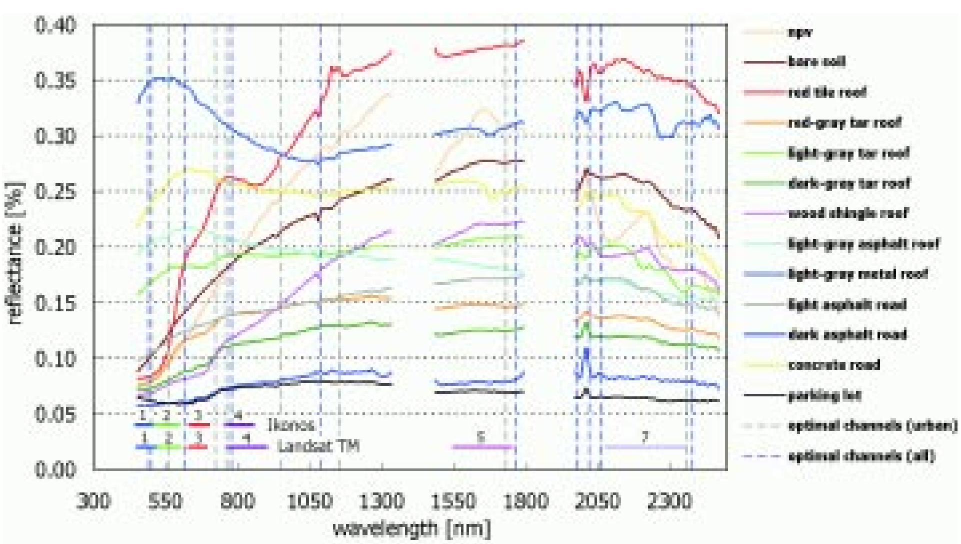

Figure 1. Mean reflectance signatures of urban land cover types, bare soil and NPV derived from AVIRIS shown with multi-spectral coverage of the IKONOS and LANDSAT TM sensor and optimal spectral bands for class separation of urban land uses (gray) and all 20 land cover types (in blue).

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data acquired over Santa Barbara, CA were used in this analysis. AVIRIS data have detailed spectral resolution, measuring 224 bands be-

Figure 2. Subset of the classification result for AVIRIS level III classification.

tween 350 and 2500nm. These data were used to simulate 4-band IKONOS and 6-band TM data. Supporting ground reference data (field spectra) were acquired to characterize the spectral properties of urban surfaces and to develop a basis for the training and validation of the image classification. Field spectra were recorded using an ASD field spectrometer to study the spectral properties of different urban surface categories and for radiometric calibration of the AVIRIS data. About 300 training and test sites were compiled using low altitude photographic ground truth flights and field mapping using a digital parcel and building dataset of the study area.

This work analyzed three levels of classification ranging from generic Level 1 (Built-Up, Vegetation, Barren, and Water) to very detailed Level 3 (distinguishing specific types of roof, road, and other land cover materials). To reduce the dimensionality of the AVIRIS data, band prioritization based on class separability measures were employed. A commonly used statistical separability measure (Bhattacharyya distance[2] or B-distance) was calculated based on the training areas for the 20 different classes. These were used to assess the spectral separability of different land cover types and to select and evaluate important spectral bands for urban land cover mapping. B-distance was also used to determine each sensor's ability to separate urban land cover types and choose most suitable spectral bands. Figure 1 plots the optimal AVIRIS channel selections determined using this procedure.

Image classification was performed on the IKONOS, LANDSAT, and AVIRIS data using a Maximum Likelihood algorithm based on the training areas. Ten optimal AVIRIS bands determined by the B-distance analysis (bands 12, 23, 30, 64, 82, 97, 146, 173, 184, 209) were used in the classification. Test areas were used for accuracy assessment.

As expected, of the three sensors tested, AVIRIS resulted in the best classification (Figure 2). The IKONOS classification showed significant spectral limitations that suggest serious problems in detailed and accurate mapping of urban land cover types with IKONOS data. LANDSAT provides an additional level of spectral information due to the additional bands in the short wave infrared (SWIR), therefore improving on the IKONOS classification. The ten optimal AVIRIS wavelengths produced the best classification results though some confusion still exists among certain cover types (overall accuracy: 78%). Much of the disparity among the sensors tested results because "optimal" spectral regions determined for urban land cover mapping fall outside of the wavelength regions of the spaceborne sensors tested (Figure 1).

In conclusion, to improve urban land cover classification, this research suggests an optimal "urban mapping" sensor including IKONOS bands plus bands at ~920 nm, ~1150 nm, ~1740 nm, ~2060 nm and ~2350 nm.

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A Tool to Facilitate Bridge Management and Application at Wisconsin DOT

The Federal Highway Administration (FHWA) has mandated that each State Department of Transportation (DOT) must determine accurate spatial locations for all bridges. DOTs typically have some spatial referencing of their bridges, but few meet the a FHWA accuracy requirements. Ground-based technologies, such as GPS, can provide greater accuracy but require field-work, which is time consuming and expensive.

An alternative is to use remote sensing data and digital image processing. However, there are several issues that must be addressed:

- Scale and data quality. Bridge data may be referenced to road data which does not have coordinates, in which case bridge coordinates can be no more accurate than dictated by the scale of the road data. Satellite imagery resolution typically ranges from sub-meter up to 30 meters. Landsat (30 m) imagery is appropriate for 1:100,000 data; sub-meter satellite imagery or ortho-photography is required for more demanding applications.
- Defining bridge location. At a small scale a bridge location might be established as a point, while at a larger scale it may be a line segment, and at a very large scale it is perceptible as a polygon, and structural features such as abutments are visible. If the location is defined as the bridge center, there are different apparent centers depending on scale. If location is defined as the mid-point between abutments, this requires a scale where abutments are visible.
- Compatibility of data with location referencing methods. Linear Reference Methods (LRM), in use at DOTs, locate bridges as events that occur at some distance from a control point along a road. Coordinates cannot be generated without a cartographic representation of the roadway. Tools that use imagery need to handle both LRM and coordinate data.
- Manual vs. automated feature recognition. Ideally a tool would analyze an image, extract its features (i.e. bridges) and return a set of locations to a database. However, the science of automated extraction has had only moderate success, with most

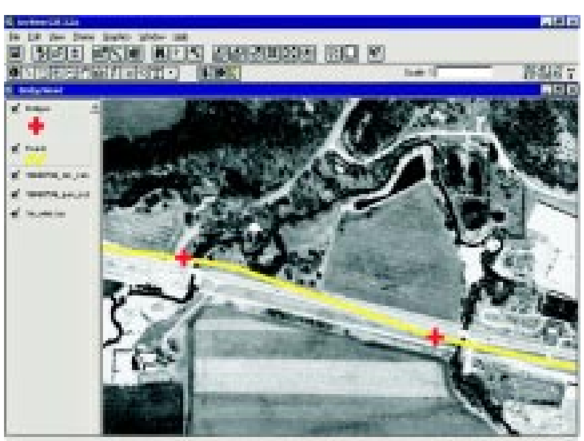

Figure 1. Bridge locations inferred from DOT linearly referenced records (red) can be inaccurate. Error in road centerline (largely the cause of the inaccuracy) is also apparent.

research focused on semi-automated techniques.

The Infrastructure team at the University of Wisconsin-Madison developed BridgeView for agencies to create and update their roadway/bridge spatial databases using remote sensing data. BridgeView is an ESRI ArcView® 3.2 extension developed using the Avenue® programming language, and runs on the Windows® NT/2000 operating system. It uses aerial orthophotographs, satellite imagery and spatial data sets to refine cartographic representation of terrain features. Users edit positions of roads and bridges by visual interpretation of ortho-imagery.

BridgeView supports a variety of data formats, and enforces spatial database and imagery concurrency by requiring data accuracy definitions. It supports ESRI® shapefiles for cartographic representations and provides an image manager (i.e., Image List) which loads images as themes. The tool contains automatic scale-change functionality and requires appropriate minimum and maximum scales for theme display.

BridgeView supports various bridge location definitions (e.g. midpoint between two abutments) through scale dependent imagery display and requiring high and low resolution imagery, as well as panchromatic and multispectral imagery. BridgeView supports datasets with various linear and non-linear location referencing methods. Images, roads and bridge locations must be accurately oriented using the same base datum. Linear locations of roads and bridges are transformed into map coordinates. BridgeView uses automated techniques and manual editing to create and update databases.

Figure 2. At smaller display scale, BrideView provides broad overview of assets and their location.

In summary, BridgeView offers the following benefits:

- It supports a variety of formats (e.g. shapefiles, Landsat, and IKONOS)
- Cartographic representations of roads can be realigned to correspond with roads in aerial/ satellite images.
- Measurement of road/bridge positions and coordinate update if recorded locations differ from actual positions.
- Update of existing LRS located data. Once edited, road/bridge locations can be transformed into more accurate linearly referenced locations.
- Creation of new bridge locations (based on text descriptions) by pointing to their locations on images and adding their attributes to the bridge database.
- Bridge locations within a horizontal error of 1-2 meters depending on image resolution and nominal scale.
- Project costs and time requirements reductions compared with using GPS receivers in the field.

Credits: Wisconsin DOT provided road spatial data and input. Contributors from University of Wisconsin-Madison include: Frank L. Scarpace, Alan P. Vonderohe and Teresa M. Adams, Principal Investigators; Raad A. Saleh, Project Director; Nick Guries, Graduate Research Assistant; Ji-Sang Park and Nicholas Koncz, PhD Candidates.

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Figure 1. The Oakland Hills, CA fires of 1991. Credit: Paul Kienitz

Emergency Evacuation: Critical Infrastructure at the Neighborhood Scale for Fire Threatened Regions of California

The transportation system invariably features prominently in news coverage of an emergency. It is the escape route as well as the means of delivery of assistance, and can sometimes be the casualty of an event. In the Oakland Hills CA fires of 1991 (Figure 1), 25 people died, most of them trapped in their cars in stalled traffic following a collision.

One aspect of planning for an emergency is to evaluate the readiness of infrastructure to cope with a sudden increases in demand, to identify weaknesses, and to put in place physical and institutional measures to address the shortcomings.

Transportation infrastructure can be defined as all assets that help convey traffic, maintain the system, and handle emergency incidents. This includes roadways, bridges, intersections, signage, communication equipment, traffic signals, traffic operations centers, and maintenance and emergency equipment. The capability of an infrastructure to handle transportation demand can be defined as the infrastructure capacity. Using standard methods, such as those given in the Highway Capacity Manual, it is possible to estimate the capacity of roadway segments, intersections, etc. The capacity of a network is not the sum total of such individual capacities, as bottleneck elements may be present, where the network is loaded with an inordinate level of demand, incurring delays. Bottlenecks are clearly where the need to provide better traffic management is greatest, particularly in time-critical situations such as emergency evacuation, or where emergency relief vehicles need to move rapidly through a congested system. Infrastructure elements may be classified as to whether they are bottlenecks or not at a given time.

Spatial information technologies coupled with micro-scale traffic simulation models help to identify bottlenecks and network clearing time. Small transportation networks in Santa Barbara and Thousand Oaks CA are being analyzed in the context of emergency evacuation. The objective is to estimate the clearing time for a small network following an event that initiates an evacuation. Figure 2 displays part of a 700 home neighborhood during a simulated evacuation. Individual cars can be seen queued along the network. This presentation is an output of the PARAMICS simulation system. For the neighborhood in question, which lies within a high fire risk area, evacuation time has been determined to be excessive, and state and county officials are now planning to help mitigate the bottlenecks identified in the simulation by widening arterials, identifying private roads that may be opened to the public in the event of an emergency, and re-allocating traffic control officers during "red flag" alerts. Public information campaigns will address alternate escape routes, and the importance of minimizing traffic demand by leaving most vehicles behind.

Figure 2. Traffic simulation of evacuation in progress, showing queueing of outbound vehicles.

The time it takes to respond appropriately to an incident at a given location is another metric by which one can measure infrastructure capability. As part of this research, tools are being developed to identify portions of infrastructure that lie outside of normal, acceptable response time standards. Another aspect of the analysis addresses loss of infrastructure: the extent to which equipment could be stranded during an emergency (for example a flooded roadway, a collapsed bridge) and not be accessible to areas in need.

Credits: Rick Church, Ryan Sexton. This research was funded in part by Caltrans.

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Discussing the Impact of Boston's Central Artery Over Time

This project applies remote sensing for 1) highway infrastructure change detection, 2) transit infrastructure change detection, and 3) land use change detection of a major transportation infrastructure project, the Central Artery/Third Harbor Tunnel in Boston, MA.

Boston is a busy and congested city served by the elevated Central Artery (CA), and facing the construction of the Central Artery/Tunnel (CA/T), which has been described as the 'largest, most complex and technologically challenging highway project ever attempted in American history.' The CA was opened in 1959 to reduce congestion in downtown Boston. An Inner Belt road was part of the plan to carry through traffic while the CA was designed to carry local traffic. The belt road was never constructed, and the Central Artery, now carrying both local and through traffic, faces extreme congestion levels and safety problems. Completion of the CA/T is expected to bring about dramatic changes to the downtown district when most of the area along the existing elevated structure, about 27 acres, is replaced by open space. The entire project is expected to be completed in 2004, including demolition of the old highway.

The past five decades, from before the construction of the Central Artery to the present stage of construction of the CA/T, present a unique case study for the application of spatial analytic techniques and remotely sensed imagery to identify and quantify the changes in land uses, and transit and highway infrastructures that have occurred around a major transportation infrastructure project, the Central Artery in downtown Boston. Spatial data and remotely sensed imagery from before the construction of the artery in the 1950s, during the lifetime of the artery, and construction of the CA/T, will be integrated and analyzed to identify and quantify the changes in land uses and highway and transit infrastructures that have occurred around this large infrastructure project.

Land use-transportation interaction is of interest to transportation professionals particularly related to large transportation projects such as the CA/T. The study of the changes to either land use or transportation infrastructure is usually carried out assuming one or the other to be a fixed control factor. A need exists to identify and quantify changes in both transportation infrastructure and land uses over time to be able to study their mutual interaction. This project provides a method for identifying and measuring the temporal changes, which have occurred around a major transportation infrastructure project.

Figure 1. Downtown Boston, 1955: early Central Artery near Faneuil Hall.

The changes in the land uses and the demographic characteristics of the different land uses are equally important in identifying impacts of the transportation infrastructure on the surrounding community. The demographic characteristics of interest in this project include population, population density, employment densities, median household income, land prices, density of residential and office buildings and their characteristics (multi family vs. single-family units, and multi storied vs. single storied office buildings), and rents. The changes in land use may occur as a total change in the land use itself, or by changes in the demographic characteristics associated with the land use. A residential zone may have become a commercial zone, or a commercial zone may now have a larger concentration of offices and employees than it did previously. Changes may also have occurred by reconstruction. These changes will be identified and quantified. Parcel data, census data, and land use layers from the different time periods obtained from Massachusetts Geographic Information Systems (MassGIS) will be used to identify the changes in land uses and land use demographics. The changes identified will be overlaid on remotely sensed imagery for further analysis. Use of remotely sensed images provides a powerful evaluation tool of an area of interest where major changes have occurred, offering a method of quickly and meaningfully conveying information. In addition, remotely sensed imagery will be used to identify other changes that were not identified in the previous step. Land use layers that could not be obtained from MassGIS will be created using remotely sensed imagery.

Figure 3. Downtown Boston, 1995: as construction begins on the depressed Central Artery Tunnel.

Figure 2. Downtown Boston, 1978: fully developed Central Artery near Faneuil Hall.

Figures 1 through 3 of downtown Boston near Faneuil Hall taken at three different time periods show the changes that have occurred in the area during the life of the Central Artery. The residential and low-density commercial area to the south of the highway and west of Faneuil Hall in the 50s has given way to open land in the 70s, which eventually changed to high-density commercial in the 90s. The roadway alignments have also changed to accommodate the changing travel demand.

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Instant Imagery Access for Multimodal Transportation Planning in Virginia DOT

The project demonstrates the usefulness of 'Instant Imagery Access' of remotely sensed imagery to transportation planning projects involving five transportation types: roads, railroads, airports, water ports and transmission systems. Remotely sensed imagery is typically used more by the GIS community than by engineers involved in transportation infrastructure planning. Routine use of imagery has been often hampered by slow delivery, high costs, and image manipulation procedures that can require the user to be a specialist. Transportation planning engineers could greatly benefit from the increased spatial and attribute information inherent in imagery, and the knowledge gained by merging imagery with their proposed design and vector data layers. This project demonstrates a methodology that brings imagery through the internet from remote image servers into the engineering workspace in an efficient and cost effective manner, and demonstrates how the decision making process required during the early stages of transportation planning can be enhanced.

The project's application of road data is interactive with Bentley's MicroStation version 8 Computer Aided Design software, and was applied to the Virginia DOT's Route 1 Location Study. This demonstration incorporates imagery and other geo-spatial data from several sources including LandSat 25 meter color; ORBIMAGE Cities digital aerial 1 meter panchromatic; Vargis digital aerial 1 foot color; ground-based GPS-referenced digital photographs, accurate road centerline vectors, ArcView parcel shape files, and other GIS vector data layers. Typical steps to incorporate imagery into a GIS workspace are: to identify image source and purchase; to order and take delivery; to clip out imagery needed for project; to convert image format and import into software; and to geo-locate image with vector data. 'Instant Imagery Access' allows the user to specify a region and workspace coordinate system, click a single button and view a list of available images covering the area. The user then selects the image desired based on the metadata shown. The selected imagery is delivered to the local display through the internet or intranet, based upon the defined workspace and coordinate box. The imagery is automatically matched to the design work area and the vector data coordinates. Implementation initially serves Bentley's MicroStation software environments although the

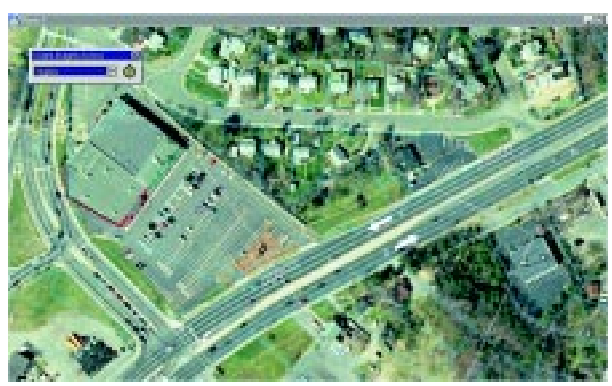

Figure 1. Northern Virginia Route-1 project plan (white lines) merged with Vargis digital aerial one-foot resolution orthophoto, Fairfax County parcel information (blue lines). Microstation Instant Imagery Access button is shown.

Figure 2. Arlington, Virginia. OrbView Cities PLUS 1m panchromatic imagery, collected April, 2001. Vector Overlay - GDT Dynamap, January, 2001. Scale approximately 1:8000.

methodology can be applied to other systems. This image server and software architecture additionally benefits users by eliminating on-site storage of massive image and vector data libraries, removing image bank maintenance responsibilities from regional DOT or contractor personnel, permitting images and vector data to be shared by several locations, and automatically matching the location and resolution of accessible images to the vector map display view.

The project team interacted with transportation planning users through technical exchange meetings and demonstrations to evaluate the acceptance and usefulness of this methodology. Transportation planning requirements for imagery use were discussed and summarized as follows:

- make image processing steps transparent to users;
- a variety of image types and scales must be available;
- imagery must be kept up to date on the servers;
- image metadata must be easily available (source, sensor type, resolution, date of collection).

Imagery is important in the early planning stages to aid in detection of sensitive areas such as parks, churches, schools, wetlands etc. During the early planning and proposal stages a subscription pricing model that allows open access to view and use imagery on screen would be important but also it should be easy to purchase and download selected imagery when necessary.

Both commercial engineering users and Government users identified benefits to transportation planning by using imagery. For Government agencies increased use of remotely sensed imagery can assist in minimizing impacts to the environment, infrastructure and traffic flow; enhance the initial project scoping; facilitate the preparation of Requests for Proposals; improve inter-agency coordination; and facilitate project monitoring. For the commercial engineering firms, 'Instant Imagery Access' can facilitate their response time to RFPs and allow them to create better briefings; assist to decrease costs, keep on schedule and minimize project risk; enhance the engineering design process; accelerate the project initiation phase; and facilitate response to requirement changes throughout the project.

In conclusion, satellite and aerial imagery, and digital photographs are required during the transportation planning stages. 'Instant Imagery Access' and new imagery subscription and other pricing models are necessary to increase the availability and common usage of remotely sensed imagery to users that have not traditionally been able to apply imagery to their daily activities.

Credits: Principal Investigator : M. Gregory Hammann, Orbital Imaging Corporation. Partners: Stan Hovey, Parsons Brinckerhoff Facilities, Inc, John Franklyn, Bentley Systems, Inc. Data from Virginia Department of Transportation.

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Application of High Resolution Commercial Satellite Imagery to Analysis of Federal Highway System Intermodal Connectors Along the Alameda Corridor

The project focus is to develop remote sensing tools for analysis of federal intermodal connectors to the Federal Highway System. The test locale is the Alameda Corridor area of southern Los Angeles County, a $2.8 billion freight rail system connecting the Ports of Los Angeles and Long Beach with the intercontinental rail system. The project is analyzing two intermodal connectors. The recent study involved the preparation of several new products for assessment. Ikonos imagery of the Washington Boulevard and Carson Yard regions of metropolitan Los Angeles was acquired. These are areas where containers on rail are transshipped to truck and then distributed via interstate highway. The primary technical work is being conducted at Pasadena's Jet Propulsion Laboratory (JPL), supported by HJW Geospatial, Inc., California State University at Long Beach's Remote Sensing Department and the NAFTA Corridor Institute.

Initially, the team assessed the application of multiple remote sensing imagery types, including IKONOS, Quickbird-2, Landsat and AVIRIS data. The data have been cross-referenced with digital ortho-photography and integrated with a GIS platform from ESRI. National transportation and census databases have been reviewed for applicability in combination with these data sets, and the results are being analyzed for value to the transportation, real estate and goods movement industries.

The study has now focused on the applicability of the Ikonos and Quickbird-2 high spatial resolution satellite imagery. The initial conclusion is that Ikonos imagery can provide a valuable contribution towards the reduction of Intermodal Connector design study costs and associated transportation planning. It was the purpose of this study to determine if costs in preparing basic data information for GIS planning of an intermodal corridor could be reduced with this new remote sensing tool.

The imagery was processed by JPL to prepare a 1 m resolution 4-band multispectral dataset that was then thematically classified with the Feature Analyst™ software developed by Visualization Learning Systems. The high spatial resolution of the data required the application of novel techniques. The multispectral product of land cover was converted to land use types based on contextual information, and used to identify optimal transportation routes and candidate lands for upgrade or changed use. In addition, high resolution air photos (6 inch spatial) were automatically georegistered to the Ikonos data where further analysis was deemed necessary by highway engineers. Other information collected by conventional means was co-registered to the GIS database.

The primary deliverable for this project is an "Intermodal Connector Analysis Tool (ICAT) Report". The ICAT will be made available to transportation planners via an internet web site developed for this purpose. It will also be hypertext-linked into the USDOT intermodal connector website, and will have links to

Figure 1. Carson intermodal connection yards. Simulated 1 meter resolution produced through convolution of 4m Ikonos RGB and 1m panchromatic.

states which have intermodal connector programs.

The Intermodal Connector Analysis Tool Report will:

- Identify the types of satellite and aerial photographic imagery evaluated, and their sources and cost,
- Identify the other types of data with which that imagery has been interfaced (such as census, transportation and land use/land cover data,
- Identify ways that these data sets were used individually and in combination to generate data specific to intermodal connectors,
- Suggest how the data can be integrated into GIS,
- Estimate the value of that data to transportation planners and other end users,
- Suggest ways in which the imagery can be used for transportation planning in other geographic areas,
- Provide a list of suppliers for the imagery and representative costs.

In addition, the internet site will be made available to other developers of transportation-related remote sensing technology, including those from the National Consoria on Remote Sensing in Transportation, to showcase their systems. In this way, leading edge technologies developed within this program can be viewed and applied by transportation planners on a national basis in one location. The Tetra Tech/JPL team is currently evaluating some of these technologies within the context of the intermodal connector analysis project.

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Traffic Flow

SURVEILLANCE, MONITORING AND MANAGEMENT

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The **NCRST-Flows** Consortium focuses research on applying space- and air-based remote sensing technology to improve the efficiency of local, regional, statewide, and interstate highway and intermodal traffic flow. Improving the efficiency of transportation systems for the 21st century will rely heavily on our ability to monitor and manage traffic flow and freight movements. To increase the capacity of safe and secure surface transportation within an increasingly limited physical space devoted to the movement of vehicles, transportation engineers, planners, and managers seek more precision, lower acquisition costs, and improved timeliness in measuring vehicular flow. Obtaining these objectives requires both increased and improved monitoring capabilities and the continued development of advanced management tools to exploit the increased quantity and improved quality of the digital data collected.

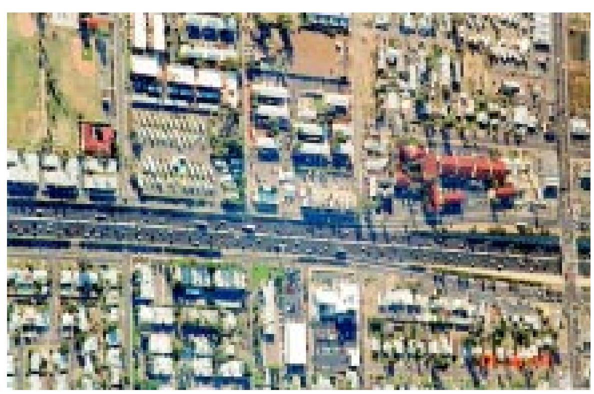

Figure 1. Freeway level of service analysis, Maricopa County, Arizona.

Figure 2. Monitoring an intersection in Maricopa County, Arizona.

NCRST-F research, development, and outreach have focused on monitoring flows over relatively long time periods and large geographic areas and managing more local flow patterns to relieve congestion and improve efficiencies. Research has also emphasized strong methodological and tool development components. The consortium has established itself as the national focal point on remote sensing of transportation flows during this time and is establishing itself as the international focal point, as well. Consortium administrators and researchers have made presentations on research results and general consortium activities and led panel discussions at regional, national, and international conferences in traditional transportation and remote sensing venues and also in new venues that emphasize the intersection of these fields. The administration team has been invited to summarize the state-of-the-practice and state-of-the-art in remote sensing of transportation flows at national conferences and is organizing an international workshop to be held in September 2002. Project participants have offered courses, workshops, and seminars emphasizing consortium work. Several unique and promising research results have already been produced, leading to research articles, conference presentations, and spin-off projects funded by other sources. In addition to research and development with mid- to long-term views, consortium investigators are also working with Technical Applications Program partners to test and conduct proof-of-concept studies that have shorter-term horizons.

In the third year, NCRST-F will place special emphasis on the links between remotely sensed vehicular flows and intelligent transportation system innovation and security concerns on the open transportation network and at critical locations, such as border crossings. The consortium has identified three priority areas for research in this third year: (1) Truck and Intermodal Flow Monitoring and Security; (2) Traffic Flow for ITS Applications; and (3) Monitoring and Information Systems for Transportation Flow and Security.

With a recent increased emphasis on security, traffic and freight flow monitoring and management take on additional dimensions. NCRST-F is moving into closer association with the use of intelligent sensor systems and intelligent transportation systems to address this widening scope. The estimation of region-wide traffic flow characteristics (average daily traffic, vehicle miles traveled, OD volumes, path flows); estimation of local characteristics (vehicle speeds, link travel times, densities, turning ratios, intersection level-of-service); identification and tracking of potential threats via trucks (carrying hazardous material, possible traffic/regulation violators, unusual driver behavior); image processing methods specifically targeted to flow and intermodal activities using core imaging technologies (high-resolution satellite imagery, LIDAR, radar, video); and planning, scheduling and acquisition of images from moving platforms for efficient collection of added information, are all areas in which NCRST-F will focus attention.

Figure 3. Arterial level of service analysis, Maricopa County, Arizona.

Examples of the research work completed by NCRST-F in several areas are provided on the following pages. Full texts of annual research reports are available at http://www.ncrst.org/research/ncrst-f/ncrst-f_home.html.

Improved AADT Estimation with Satellite Imagery for State Transportation Departments

We are investigating the use of high-resolution imagery from satellites and aircraft to improve the estimation of average annual daily traffic (AADT), a traffic statistic fundamental to many transportation documentation, planning, and design tasks. State departments of transportation (DOTs) and national agencies around the world invest heavily in personnel and equipment to collect data supporting AADT estimation. Presently, these data are collected from sensors placed in or on the roadway surface to detect vehicles passing a point in the highway.

Satellite- and air-based imagery can provide additional data for AADT estimation. Sensors carried on satellites or aircraft avoid the danger to ground crews and disruption of traffic accompanying the placement of traditional ground-based sensors. They can access remote highway segments easily and provide a spatial perspective unavailable from ground-based sensors. Vehicles are evident in high-resolution satellite imagery (Figure 1a). Moreover, we are developing algorithms that automatically identify the vehicles in such imagery (Figure 1b). However, imagery provides "snapshots" of vehicle densities at time instants, whereas current AADT estimation methods use traffic volumes measured over an extended interval of time — on the order of a day.

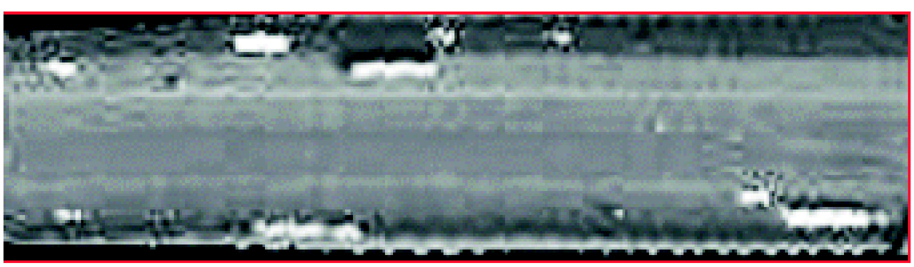

Figure 1a. 1-m panchromatic IKONOS image of highway segment.

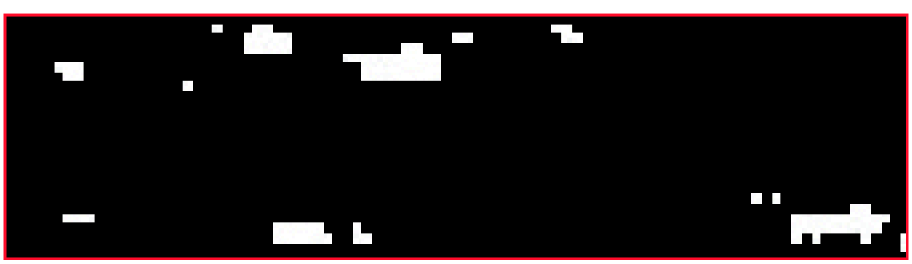

Figure 1b. Binary image resulting from automatic processing of Figure 1a image.

Traffic engineering principles can be used to convert image-based densities to equivalent vehicle flows for AADT estimation, but the time intervals corresponding to such flows are very short. (For example, the imagery used in Table 1 led to time intervals between 8 and 15 min). Time-of-day factors can be used to expand short-interval flows to equivalent daily volumes, but their use is not common in traffic monitoring programs and such expansion would introduce previously unknown estimation error. We have been modeling this error and quantifying it using loop detector data. Results to date lead us to believe that the error is small enough that image-based data can be of substantial value in estimating AADT.

We are also empirically estimating AADT from satellite- and air-based imagery for selected Ohio highway segments and comparing these

Segment (platform,date)	Density (veh/mi)	Segment Length(mi)	Estimated Flow (vph)*	Image based AADT**	Conventional AADT***	%Error Image based vs. Conventional AADT
I270@US23 (IKONOS,05/29/01)	46.17	8.08	3102	49560	50562	-1.98%
171@US62 (airplane,11/30/95)	24.90	7.47	1625	32742	31611	3.58%
171@US62 (airplane,10/29/96)	24.64	15.06	1649	30661	32970	-7.00%

* Based on speed limit
** based on hourly factors, then ODOT seasonal factors.
***Based on published AADT from most recent year and the corresponding published yearly growth factor

Table 1. Empirical comparisons of image-based and DOT-produced AADT estimates.

estimates to traditional estimates produced by the Ohio DOT. Present results (Table 1) are surprisingly good, especially when considering that they are produced with very crude time-of-day factors that can be improved with further research.

Table 1 results are encouraging, but real value would come when regularly using image-based estimates on a widespread basis. We therefore developed software to simulate AADT estimation errors with and without the use of satellite-based data. The ground-only and ground-and-satellite AADT error curves are plotted as a function of "ground crew network coverage cycles" (the number of years ground crews need to collect two daily samples on each segment in their statewide highway networks). The different ground-and-satellite curves simulate the use of 1 m data collected from two, one, and "one-half" sensors, subject to satellite orbit, cloud cover, and lighting constraints. We call this Equivalent Satellite Coverage (ESC) of 2.0, 1.0, and 0.5 (ESC = 0.5 corresponds to using only 50% of the satellite-based data collected in a state.) The curves show that adding satellite-based data to ground-based data markedly decreases the estimation error across the set of highway segments for all coverage cycles.

State DOTs are encouraged to cover all segments in their system on a 3-year cycle. The ground-only curve in Figure 2 shows an AADT error of 0.68 with a 3-year cycle. The error on the curve corresponding, for example, to ESC = 0.5 with a 10-year cycle is only 0.57. That is, when using only 50% of the satellite data collected in a state, ground-based resources could be decreased so that crews cover highway systems in 10 years, rather than 3, while still decreasing AADT errors.

Although results to date indicate great potential for reducing both estimation errors and ground-based sampling resources, the results are based primarily on simulations. We are expanding our comparisons of satellite-based and traditionally estimated AADTs and refining the image-based estimations by developing better methods for expanding short-interval flow rates. We are also investigating the potential for this type of estimation for truck traffic, which has different time-of-day characteristics, can be observed from coarser resolution satellites, and travels in corridors that can be targeted with pointable satellite sensors.

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Determining GPS-generated locations of emergency vehicles, snowplows, long haul trucks, and other fleets of vehicles for managing operations and planning is becoming fairly standard practice. The greatly reduced costs and size of GPS equipment arguably make it the best way to monitor locations of

Can Dynamic Locations of Local Traffic Movement be Monitored Using Image Backgrounds?

these vehicles now and in the foreseeable future. We see the potential for an even greater use of these capabilities, integrated into the daily lives of individuals, by using imagery as a backdrop upon which to dynamically display the GPS determined locations of vehicles. A segment of the population readily identifies with imagery of their local area, being able to point out features quickly on the imagery of meaning for them. This work builds on this assumption and on the reduced cost of the available equipment.

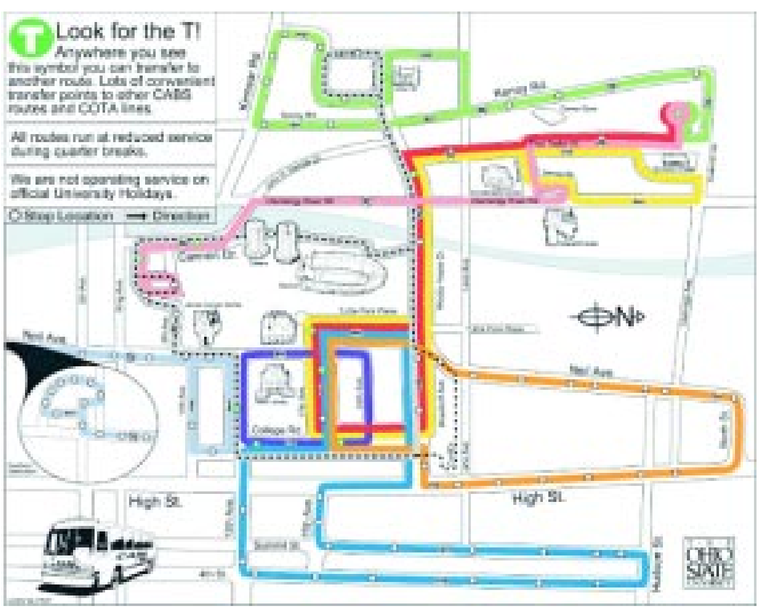

Figure 1. Campus bus routes – map form.

As one of NCRST-F's first year Technology Application Partners, Bridgewater State's Moakley Center for Technological Applications placed selected GPS-generated locations of buses in the Cape Cod, Massachusetts area on hard copy air-based imagery. The product served as visual support when investigating suspected driver deviations from scheduled routes. This knowledge and the experience of Moakley Center with static, hard copy application has motivated a more dynamic, electronic extension of the underlying concept. 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 in Columbus, Ohio. Each bus is equipped with a GPS-based locator system that provides on-line real-time passenger information and off-line performance monitoring of bus operations. Individuals can access the location of the operating buses at any given time on the network from their computer. Initially the bus locations were displayed in real time at a web site on a crude map background (Figure 1). As an experiment, NCRST-F, incorporating the use of an image backdrop (see http://blis.units.ohio-state.edu/aerial), is now providing an option whereby users can also view the actual dy-

Figure 2. Campus bus locations on image backdrop.

namic (updated every minute) bus locations on an image backdrop of the area (Figure 2). The increased "high tech" and more aesthetically pleasing appearance of the information provides a more pleasant experience to those visiting the site. The use of image backdrops offers similar potential for the many transit agencies around the world that track vehicle locations dynamically and convey this information to the public. If marketed well, such an appearance could generate a more positive image and greater support among current users and non-users of transit systems. In addition to viewing the dynamic transit system on a desk or laptop computer, existing kiosks with screens could be outfitted with image backdrops at bus and train stops, as well as in major office buildings.

The idea can be integrated into daily use in other ways. One immediate application would be for those school districts whose school buses are equipped with GPS equipment to allow parents to view the progress of school buses toward pick-up and delivery of their children. This would not only help parents, but it also would help school administrators tasked with the responsibility to ensure the safe pick-up and delivery of children to and from school each day. The recent errant school bus trip from Pennsylvania to Maryland would have been caught much sooner. The use of this technique could prove especially useful for special education school buses that are subject to lengthy trips and longer stops at each pick-up and delivery. Another use would be with delivery and service repair trucks. Currently a customer is commonly given a time frame of 1 to 4 hrs for the delivery of goods or a repair service. By posting the daily schedule and allowing users to view the progress of the delivery or service truck along that schedule in a more readily identifiable and spatially familiar format, the customer could better plan his/her day. This information would not only serve to make the system more efficient but could remove anxieties when schedules are not being met.

Additional enhancements to such a system would include the capability of introducing audio identification of prominent structures and streets that are visible on the image backdrop (available to the user by clicking on the feature), the highlighting of planned routes, and the ability to present an average progress time for movement along a thoroughfare (either based on historical records, or in real time in connection with other ITS sensors). Although we have concentrated this discussion on the transit of people, many of the same enhancements would be a value to the transportation of hazardous materials, goods of high value, or classified documents or objects. Given the current need for and emphasis on security and the apparent acceptability of imagery by users, this simple low cost innovative use of imagery as a backdrop to enhance information about transportation flows offers great returns for relatively modest investments.

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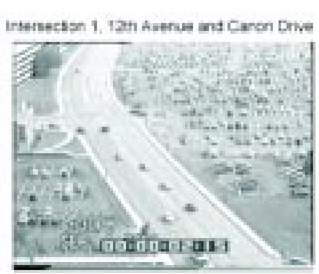
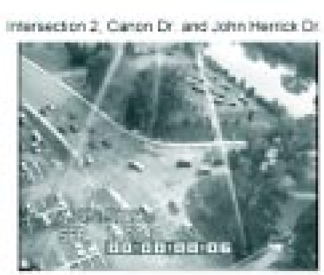
Can Bird's-Eye Views of Transportation Networks Help Mitigate Urban Congestion?

This research demonstrated that bird's-eye views can observe vehicle movements through intersections, and that their travel times along segments of the roadway can enhance significantly 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 in real-time to address the ever increasing problem of urban congestion. It is valuable to extend this research to generalize the results to more complex networks, explore the use of multiple airborne surveillance platforms, and quantify explicitly the impact of bird's-eye views on traffic management and congestion mitigation.

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 are accurate estimates and predictions of current and future traffic conditions. Therefore, management methods often employ network flow models that use data collected by a surveillance system to estimate 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. This research focuses on the role of various types of surveillance data in the real-time estimation of dynamic OD flows.

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 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 pro-





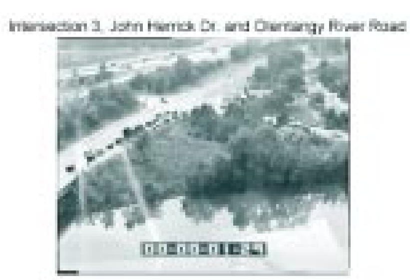


Figure 1: Sample frames of the three intersection views.

cessing 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 could improve the accuracy of the network state estimates along with traffic predictions and, consequently, resulting in more effective traffic management. The objective of this research is to quantify the value of using intersection turning fraction and link travel time measurements, which are available from airborne surveillance systems, in estimating OD flows in real-time.

Four scenarios reflecting the availability of different types of surveillance data are specified. Scenario 1 represents the base-case and consists of the estimation of OD flows using only real-time point flow data typically measured via traditional ground-based single loop detectors. Scenario 2 introduces real-time airborne-based sensor data on intersection turning fractions. Turning fractions are combined with point flows in estimating OD flows. Scenario 3 introduces real-time airborne-based sensor data on link travel times. In this scenario travel times are combined with point flows in estimating OD flows. Finally, scenario 4 is a combination of scenarios 1, 2, and 3 where point flows, turning fractions, and link travel times are used jointly to estimate OD flows. The value of using the various types of data are then inferred from the quality of the OD flow estimates realized under each of the four scenarios.

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. The cameras were positioned such that all the legs of the intersections could be partially or completely observed. Figure 1 shows the three intersection views and Figure 2 shows the abstract representation of the network to which they correspond. The video images were digitized and processed using a combination of manual and automated methods to obtain the necessary data to carry out the OD flow estimation under each scenario (for actual applications, video images must be processed automatically).

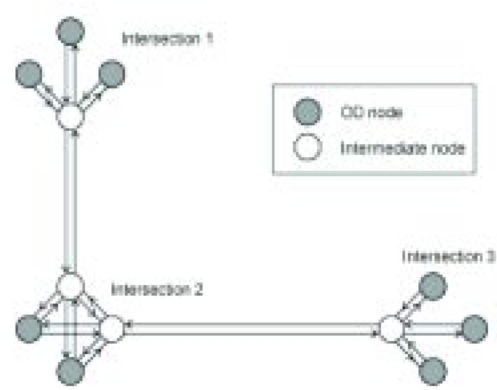


Figure 2: Network representation.

The estimation results revealed two main conclusions regarding the subject network. First, using intersection turning fraction data significantly improves the quality of the OD flow estimates. Second, using link travel time data in addition to turning fractions 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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Traffic Level of Service Monitoring and Real-Time Management in Arizona

Effective management of transportation facilities requires information on their use. This is true in the two contexts of monitoring the traffic performance and of managing traffic in real time. However, traditional methods for collecting traffic information rely on techniques that: 1) are strictly local in nature (e.g., loop detectors in the pavement); 2) are expensive to collect (e.g., test car methods to obtain travel times); and, 3) depend on questionable assumptions to obtain desired measures of performance (e.g., speeds and densities). Satellite and airborne platforms are alternative data collection platforms that can be used to collect traffic measures across broader spatial scales, giving the desired performance measures directly.

The primary remote sensing platform to date has been aerial video recorded from a helicopter. Three helicopter flights have been made using a special set-up that included a mounted commercial off-the-shelf digital video camera and a Global Positioning System receiver. Ground data were collected simultaneously during each flight for validation. Figure 1 is a sample image showing the field-of-view and relative size of vehicles in the image. The flights are typically conducted at an altitude of 1000 ft above ground, giving a field-of-view of about 800-1000 ft.

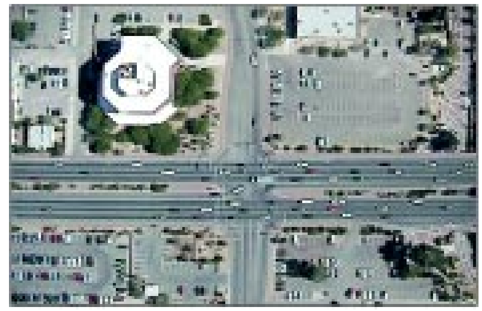

Figure 1. Sample image from aerial video.

The collected data were analyzed to establish the traffic variables that could be measured and the accuracy of those measurements. It was found that speed, acceleration, flow, density, spacing, headway, queue length and platoon dispersion, among others, can be estimated from the data (Figure 2). Sampling of video frames between 1 and 2 sec provided accurate estimates for most of these variables. As part of these experiments, travel times on an arterial street were also determined by following a pla-

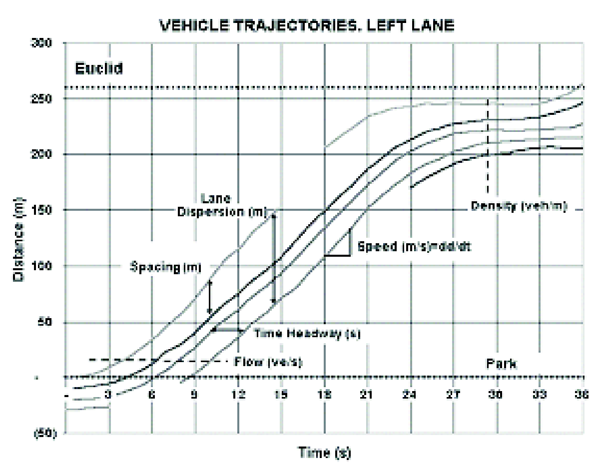

Figure 2. Vehicle trajectories.

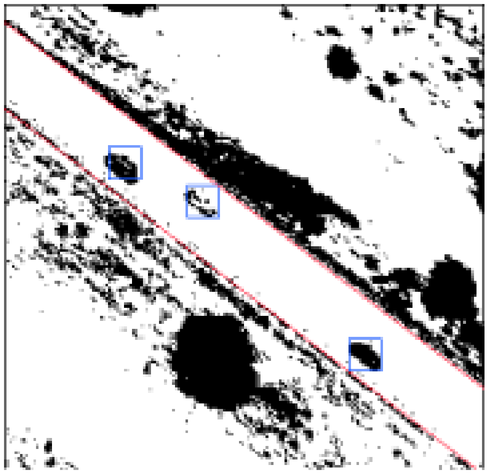

Figure 3. Edge detection sample frame.

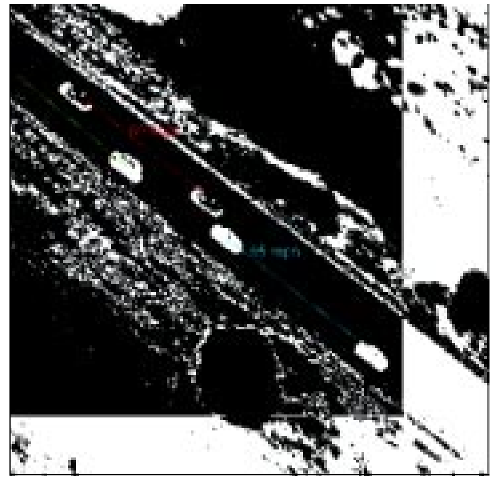

Figure 4. Image registration and subtraction.

toon of vehicles as it progressed along the arterial. The technique provides a larger sample size per run than that obtained from test vehicles and supplies detailed information, including link by link travel time and estimates of within-platoon and between-platoon travel time variations. Table 1 presents data obtained during the experiment.

Because the manual processing of the video is time- and resource-intensive, automated techniques for video image processing are being developed. An algorithm capable of detecting vehicles and measuring their speeds from the aerial video has been developed. The basic operations performed by the algorithm are edge detection (Figure 3) and image registration (Figure 4). When vehicles are matched between two frames, their speeds can be estimated directly. To date, the system has only been used in freeways; further refinement is necessary to extend its applicability to arterial streets.

Our work suggests there are many traffic parameters that can be measured using remotely sensed data: flow, density, speed, acceleration, platoon dispersion, headway, turning ratios, lane utilization, queue length, intersection delay and travel time. Although the cost of aerial video is higher than the traditional means of traffic data collection, the information it provides typically requires performing several different types of traffic studies. In most cases the cost of independently performing travel time, density, turning counts, speed and delay studies would be higher than that of performing an extensive aerial traffic study. As a result, the aerial video may prove to be cost-effective, once the processing of traffic parameters from the imagery is fully automated.

Checkpoint	Distance (km)	Average Travel Time	Average Link Speed (km/h)
Euclid Ave.	0:00		
Park Ave.	0.26	0:01:03	15.1
Mountain Ave.	0.69	0:02:18	20.2
Cherry Ave.	1.08	0:02:43	57.1
Campbell Ave.	1.50	0:04:11	16.9
Tucson Blvd.	2.29	0:04:58	60.5
Country Club Rd	3.08	0:05:51	53.7
Alvernon Way	4.69	0:07:36	55.2

Table 1. Average travel time for a 9 vehicle platoon (1 travel time run).

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Estimating Traffic Flow from the Air in Columbus, Ohio

Aerial photography is currently being utilized in the private sector for traffic flow monitoring. Aerial photography has proven to be a cost effective approach for obtaining both quantitative measures of segment performance as well as qualitative interpretations of flow conditions. An assessment of current practices, identification of companies providing these services, characterization of key components of these provided services, and an outline of planning organization/agency needs for utilizing such services has been documented.

Traffic flow characteristics are fundamental to understanding a local or regional transportation system. An important and encompassing summary indicator of performance is level of service, which is a qualitative interpretation and/or a measure of the effects of many factors (speed, travel time, traffic interruptions, safety, comfort, operating costs, volume-to-capacity ratios). To assess level of service or other related traffic measures, flow characteristics must be observed.

Traffic flow is essential in regional analysis, either in managing congestion (real time and short/long term) or coordinating where expansion, renovation and/or extension should take place. As such, traffic flow serves as a basis for investment decision and

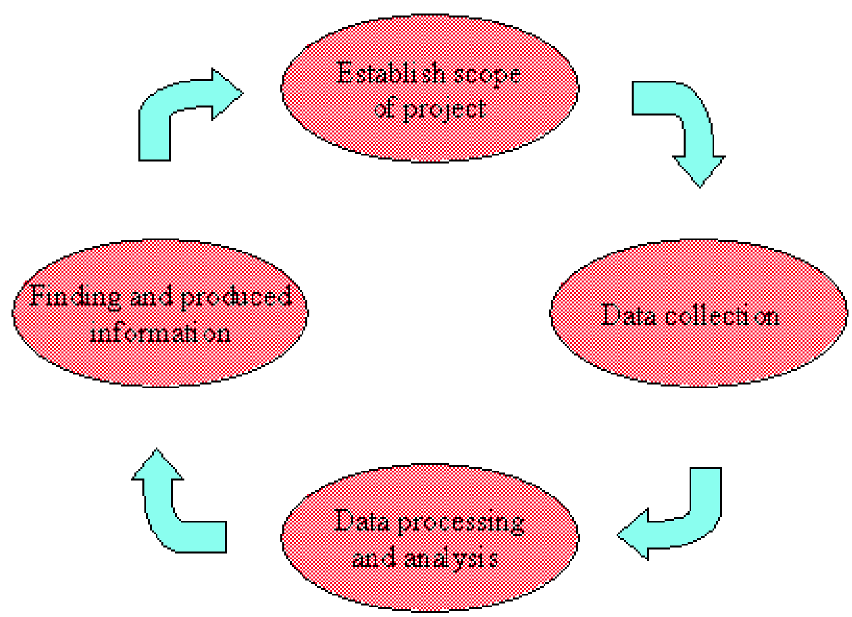

Figure 1. Aerial monitoring survey of traffic flow.

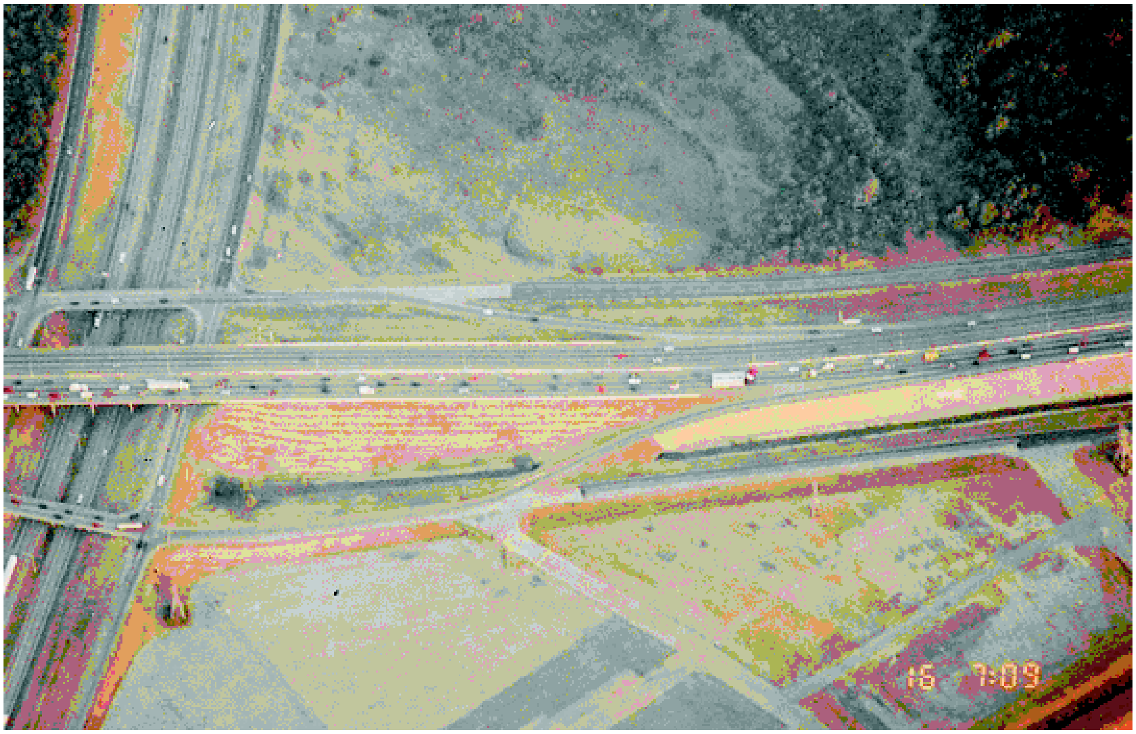

Figure 2. Aerial photograph documenting roadway segment conditions.

regional policy. The ability to work with observed traffic flow conditions is vital because it reflects reality, rather than being a perception of an individual or group of people. Traffic flow is also a central aspect of origin-destination travel.

There are four inter-related components in establishing a monitoring project for a region (Figure 1).

A monitoring survey of regional traffic flow typically utilizes a helicopter and fixed-wing aircraft, with a pilot and one or more survey personnel. The surveyors note observed conditions along roadway segments complemented by overlapping aerial photographs (Figure 2). This information is processed, reported, and interpreted for the commissioning agency.

Produced information typically includes a database of vehicle counts by segment at each observed time interval, overlapping aerial photographs, qualitative interpretation of traffic flow conditions, and other multimedia narratives of system/segment performance.

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Remote Sensing Applications in Transit Operations in Cape Cod (CCRTA) and Amherst, MA

Remote sensing and spatial information technologies were applied in two areas: the assessment of transportation demand management (TDM) projects and the assessment of regional transit capital infrastructure projects.

The TDM assessment tool was developed and tested using several TDM projects on Cape Cod – downtown trolleys, park and ride shuttles, and an intermodal shuttle to the National Seashore and other venues. The Cape Cod Regional Transit Authority's (CCRTA) transit and paratransit vehicles were all equipped with state-of-the-art global positioning system (GPS) based automatic vehicle location (AVL) systems. Every 60 seconds the AVL geo-spatial data was transmitted to the GeoGraphics Laboratory at Bridgewater State, where it was mapped on the web for consumer travel planning and archived for TDM evaluation. The TDM assessment tool recreated the travel patterns of the TDM project vehicles by tracking the AVL data on high-resolution digital orthophotos. The individual vehicle's GPS-based location data were associated with geospatial data collected by the mobile data computers on passenger boarding and alighting and electronic fare payment. The resulting analysis provided the CCRTA management with unprecedented geographic decision support on the management effectiveness and efficiencies of contract operators and individual drivers. It also provided unprecedented quality assurance and quality control (QA/QC) for transit and paratransit information systems.

Figure 1. Bottom view of MAV showing remote sensing pods under wing.

In the process of evaluating parking lots associated with park and ride shuttles, the project highlighted the need for inexpensive remotely sensed imagery with high spatial and temporal resolution. Previous research indicated that to evaluate the effectiveness of parking and traffic management schemes, imagery had to be available within a 10-min period and with a spatial resolution of 6 in. A prototype micro aerial vehicle (MAV) was developed and tested as a part of the project. The MAV carried two video cameras with a real-time 2.4 GHz downlink: a wide angle forward facing lens for piloting the aircraft and a vertical telescopic lens for a sighting camera attached to the wing. The camera was an off-the-shelf 35-mm auto-focus automatic rewind camera that was triggered by a servo (mechanical arm) hitting the shutter button at a radio signal from the 75 MHz hobbyist's radio controller. The MAV incorporated state of the art devices to assist the pilot/ photographer, including wing leveling and altitude hold. The MAV also included safety devices, such as an emergency parachute deployment and engine shut-off when the radio signal is lost with the controller. The MAV is hand-launched and reaches operating altitude in about 90 seconds. It produces real-time high-resolution digital video stored on an off-the-shelf 8 mm portable video player. The 35-mm color photography can be processed at a local 1-hr photo shop with close to 1-in. spatial resolution. In addition, miniaturized thermal infrared (IR) cameras are now available that can provide video-based thermal emissions of objects, albeit at considerable expense.

Figure 2. Photo from MAV of TDMA area parking lot and commuter rail.

Following the September 11th terrorist attacks on Washington and New York, the usefulness of the MAV in providing transit infrastructure security beyond TDM assessment became readily apparent. With the support of RSPA and the FTA, the project staff met with transit security professionals to develop a draft specification for commercial off-the-shelf radio-controlled aircraft with short take off and landing (STOL) and vertical take off and landing (VTOL) as a remote sensing platform for transit security and anti-terrorism.

The second product used remote sensing and spatial information to assess the impact of regional transit infrastructure on land use. The University of Massachusetts Transportation Center researchers used 30 years of archived high-resolution imagery and land use inventory databases to analyze the relationships between changes in land use and the development of FTA service and methods demonstration (SMD) in the Town of Amherst, MA and surrounding towns. The SMD project featured transit supportive incentives, such as differential pricing of parking, fare free transit, and high frequency service with extended hours to dense residential and retail attractions. The researchers integrated GIS point and line databases of historical transit bus routes and bus stops with historical digital orthophotos. These data were used to create a time series, noting the positive relationships between high quality bus services and supportive land use planning and regulation.

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Road Network and Corridor Planning Tool for Maine DOT

Corridor selection is a multiple step process that requires many iterations to define costs and evaluate potential impacts. Remote sensing data and Technology Service Corporation's (TSC) software can be employed both as an aid to the DOT engineers during the initial definition of corridors and as a means to evaluate the relative costs and impact of various corridor options.

TSC performed two separate projects under its U.S. Dept. of Transportation sponsored research effort, both with the State of Maine DOT. TSC quantified the cost and accuracy of performing road database updates using automated road extraction processing from multispectral imagery collected by the Ikonos satellite. TSC compared the cost and accuracy of performing road updates using both automatic techniques and manual road designation in the remotely sensed imagery. The results were also compared to the process currently employed by Maine DOT (ME-DOT). TSC conducted a state outreach survey and concluded that, while promising, the automatic extraction of roads from satellite imagery is not economically viable because of the expense of such imagery. Future government-sponsored remote sensing satellite programs and/or more affordable commercial imagery may change this situation. In the meanwhile, TSC will apply its successful automatic road extraction algorithms to conventional airborne imagery.

The second project identified a much better application of remote sensing technology. TSC examined preliminary corridor planning for an I-395 extension project in Bangor/Brewer, Maine. TSC estimated the cost for various approaches and their relative performance by comparing candidate corridors that were selected by traditional manual and automated techniques.

The routes of new highways are currently determined by DOT engineers by first defining 1000-ft wide corridors using large-scale spatial data, such as the USGS topographic maps. A large number of candidate corridors are initially determined during brainstorming sessions and are proposed as options. ME-DOT, a

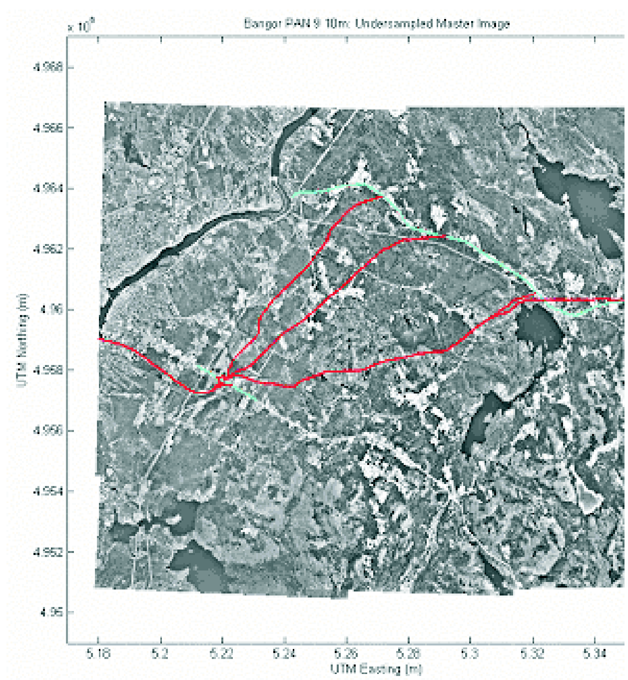

Figure 1. Corridor options overlaid on NAPP photos.

public advisory committee, and many public meetings sponsored by the Federal Highway Administration and the ME-DOT then reduce this corridor set through a process of closer inspection. The goal is to identify the single option that meets all requirements and has the minimum negative impact on local communities. Discussions with ME-DOT engineers indicate that the total cost of this process for I-395, including environmental assessment, is expected to range from $500K to $750K.

TSC developed automatic corridor planning software that uses commonly available spatial data for the first-cut route selection. The tool employs USGS Digital Terrain Elevation Data, USGS Digital Line Graph roads and the USGS National Land Cover Data set to identify the land cover areas within the corridor planning region. This data is freely available from the USGS and can be downloaded from their web site. Therefore, the only cost associated with such data is the time to select, download and import the necessary files into the software.

The corridor planning software tool processes the USGS spatial data, and allows the DOT engineer to define costs associated with road construction, as a function of terrain slope, terrain cover, existing road upgrades and/or crossings. Optimal corridor alternatives, which minimize construction cost and environmental impact, are then identified using a simple point-and-click interface. The DOT engineer simply identifies the start and end points to generate and display the optimal corridor. Figure 1 illustrates four I-395 extension corridor options that were generated using the remote sensing corridor planning software developed by TSC. These corridors are overlaid on a composite set of National Aerial Photography Program (NAPP) photographs obtained from the USGS. The DOT engineer also has the option of manually defining corridors using a point-and-click interface or loading proposed corridors in standard GIS format. The corridor costs can then be evaluated and tabulated for comparison.

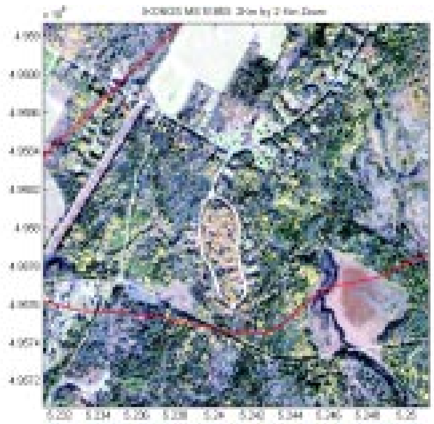

Figure 2. Corridor options overlaid on high-resolution imagery.

The DOT engineer can display these generated corridor options on high-resolution imagery, such as from the Ikonos satellite, to assess the impact on the local area. The high-resolution imagery allows the DOT planner to immediately see the proximity of houses, farms, factories, water bodies and other environmentally sensitive features that impact corridor selection. Figure 2 illustrates this capability by showing the proposed corridors overlaid on Ikonos high-resolution imagery. The proximity of the corridor alternatives to the residential development is clearly visible in this display and takes good advantage of emerging commercial satellite sources. The confined areas under consideration for corridors make the imagery economical.

Credits: Steven Jaroszewski and Allan Corbeil, Technology Service Corporation; Dale Peabody, Ray Faucher and Kevin Riley, Maine DOT.

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Multimodal Aviation Infrastructure Planning and Development at Portland, ME Airport

Currently there is a knowledge gap among transportation planners representing different modes of transportation. Due to inherent differences between air and surface transportation, this is often the case between airport planners and developers and their counterparts involved with other modes of transportation. This gap is apparent in several airport projects including proposed highway light poles and signage that could obstruct airspace surfaces, growth limitations imposed on a medium-sized hub airport due to poorly planned airport access roads, and expensive land acquisition programs at one of the nation's largest airports to accommodate infrastructure development. While this gap has existed since the beginning of aviation, the problem has worsened as urban development and airport expansion have filled the open areas around airports.

Imagery can help close this knowledge gap with information that can be applied to a wider focus area than airport planners have traditionally surveyed using aerial photogrammetry and with more information than GIS initiatives usually provide. More specifically, remote sensing offers airport planners and developers a cost effective method of broadening their planning area so that the impact of their infrastructure development and flight operations can be better understood by the regional transportation planners and land developers with whom they interact. Remote sensing, however, is not just a means to obtain broader coverage. It also offers the ability to identify patterns of development and environmental change, as well as specific features that are relevant to airport planners (Figure 1). The location of buildings, the density of housing, growth behavior of vegetation and the suitability of terrain for development are examples of the type of data that remote sensing can offer to the airport planner.

Figure 1. Land use map around an airport.

The objective of this project is to apply remotely sensed data recently collected for the Portland International Jetport in Maine (Figure 2) to form an easily deployable GIS solution that can be used by Jetport, City of Portland, Greater Portland Council of Governments and Maine DOT transportation planners and analysts. The specific goals of this initiative include:

- Identifying urban growth patterns that can constrain future airport development
- Evaluating the effect airport configuration changes can have on surrounding transportation corridors and land areas
- Illustrating areas where road construction and land development can come into conflict with airport operations
- Showing that remotely sensed data are cost effective in supporting regional planning around an airport.

The final deliverable of this initiative will not only be a toolset that Portland area transportation planners can use, but a knowledge base of factors and issues that need to be considered by each of the thousands of airports in the U.S. that are expanding in urban environments that are also growing. This information will include a clearly documented methodology and specifications that other airports can use to develop similar solutions for themselves.

The detailed documentation described above is not enough to ensure that a successful solution will be acceptable nationally. This is especially true when that solution involves a new technology. To encourage acceptance of remote sensing in the aviation sector, and the widespread application of the solution being proposed, the project plan includes creating three scenarios that will be deployed to a variety of technical and non-technical users via an interactive web-based application using ESRI's ArcIMS.

Figure 2. Aerial view of Portland International Jetport.

Since the final documentation and web-based application are intended to benefit many airports, a second implementation of the tools will be carried out at Anchorage International Airport (Figure 3). Strategically, Anchorage is an important airport for domestic and international passengers and cargo. A large amount of remotely sensed data has been collected for the area around the airport. Paired with the CADD and other sources of spatial data the airport has already developed, the methodologies and solutions developed by this project should further establish the usefulness of these tools.

Figure 3. Aerial view of Anchorage International Airport.

The work plan has been divided into five stages beginning with interviews to better understand the needs particular to Portland followed by data collection and analysis stages. The analysis stage will determine the success of the project by measuring the value remotely sensed data bring to transportation planning in and around an airport. The fourth stage will deploy the information created to Portland area users and others interested in applying the solution to their environs. The final stage will produce the deliverables and ensure they are conveyed to potential users in a successful manner.

By establishing the value remotely sensed data bring to airport planners and their non-airport counterparts, this project hopes to alleviate many of the infrastructure expansion problems facing airports throughout the country and in doing so encourage more proactive and compatible land use and transportation planning around airports.

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Educating Regional Database Development for Transportation Planning

Remote sensing and GIS technologies can be useful to develop transportation planning tools.

Several tasks were developed for this project. Methodologies to demonstrate the use of remote sensing imagery and GIS technologies for identification, characterization and mapping of selected transportation planning features included the following:

- Refined Veridian's Change Vector Analysis and Hybrid Change Detection algorithms to identify areas of significant urban change from Landsat imagery
- Developed road feature coefficients to create and extract roads from an Ikonos-based road feature image
- Incorporated these tools into a software package, CAFÉ-T (Classification and Feature Extraction Transportation), as an extension of ERDAS Imagine a widely-used image processing package (figure 2).

Criteria and metrics were also developed for an evaluation of: a) time and cost savings over traditional methods/data sources, and b) related improvements in information quality from remote sensing-derived database layers. Specific metrics included:

- Established cost framework for detecting and mapping changes from Landsat imagery
- Established cost framework for extracting road features from IKONOS imagery
- Compared manual extraction of roads with the CAFÉ-based extraction; cost advantages for this extraction process were demonstrated.

Veridian supported the widespread distribution of project-developed data, methods and tools to the transportation planning community. Specific accomplishments included:

- Developed and deployed an interactive mapping site to display project-derived imagery on the Pima Association of Governments Regional Data Center site (Figure 1)
- Developed and conducted four workshops/presentations, reaching over 100 transportation planners, engineers, and researchers in Lansing, Michigan; Tucson, Arizona; San Diego, California; and Santa Barbara, California
- Develop educational materials supporting the training needs of

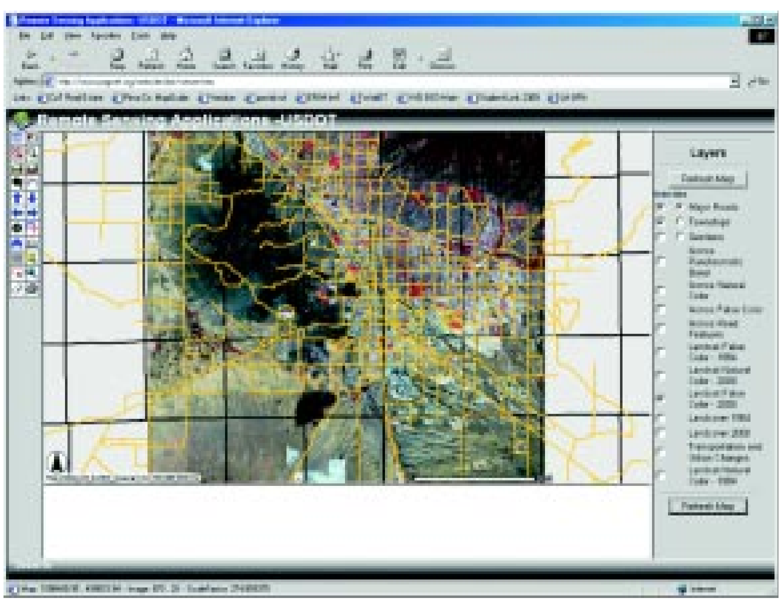

Figure 1. Interactive mapping site, hosted by Pima Association of Government's Regional Data Center, showcases the project results.

Figure 2. An on-line tutorial including notes, exercises, and additional links is also hosted by Pima Association of Government's Regional Data Center.

local, regional and state transportation planners on the use of these data sources, methods and tools

- Developed a set of comprehensive training materials for the workshops to include lecture notes and slides, workshop exercises, and sample data
- Developed an interactive version of these materials (see web site http://www.pagnet.org/hostedsites/usdot).

Although Veridian's CAFÉ-T tools demonstrated robust capabilities to detect, characterize and map land cover changes consistent with urbanization and road development, the road feature extraction tool does not consistently out-perform manual extraction as had been hoped. The spectral aspects of the road extraction issue were explored and the procedures developed were successful in developing preliminary "road feature" coefficients from Ikonos imagery. These coefficients transform Ikonos multispectral imagery into a grayscale image in an attempt to maximize the contrast between roads and non-roads. The next step in the process is to extract the subset of pixels that represent roads. These candidate pixels often contain materials consistent with roads (e.g., parking lots, roof tops), but do not have shapes consistent with roads (i.e., they are not long and narrow.) It is hoped that the relatively unique spatial/shape characteristics of roads can be leveraged into an improved extraction process. Subsequent research should be focused on the spatial aspects of this problem.

Contributors: Christopher Chiesa, Veridian Systems; Michigan DOT; Pima County (AZ) DOT; Pima Association of Governments; ERDAS; Space Imaging; ESRI; and ICARD.

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Assessing Aquatic Plant Infestations in Navigable Waterways in Rio Grande River, Texas

Millions of acres of surface waters in the United States are infested with non-indigenous aquatic plants. Aquatic plant infestations impede commercial and recreational traffic through navigable waterways, block ports and ferry terminals, and exert damaging pressure upon transportation infrastructure (e.g., bridge piers). Furthermore, canals and rivers act as corridors for the spread of invasive species outside their natural range. Water hyacinth, waterlettuce, and hydrilla in particular have been documented as causing significant obstructions to commercial and recreational traffic in navigable waterways (Figure 1).

Timely, accurate information on aquatic plant distribution and density is required both by public agencies charged with managing navigable waterways, and by private companies engaged in control efforts. Traditional field-based mapping and monitoring present several challenges, including inaccessibility of areas for field sampling, rapid changes in aquatic plant location, extent, and density, and budget constraints on field work. Remote sensing-based methodologies can aid managers in detecting infestations, prioritizing areas for control efforts, providing information on plant extent and density for estimating control costs, and for assessing the effectiveness of control operations.

TerraMetrics, Inc and its cooperators are evaluating satellite and airborne imagery for mapping emergent invasive aquatic plant cover, and to assess the effectiveness of the AquaSolutions' AquaPlant Terminator mechanical cutter for controlling plant infestations (Figure 2). The study is targeting a water hyacinth infestation on the lower Rio Grande River, Texas. Two Aquaplant Terminators were used on water hyacinth blockages on the Rio Grande River in August 2001, and additional cutting was performed during the field sampling operations.

Figure 2. Mechanical control of invasive aquatic plants using the AquaSolutions' AquaTerminator machine.

Several approaches are being tested: 1) mapping water hyacinth cover within a waterway using conventional classification to produce maps of plant extent and cover; 2) developing regression equations relating water hyacinth cover, biomass, and

Figure 1. Complete blockage of a waterway by water hyacinth.

height to spectral reflectance, and applying the equations to multispectral imagery to produce continuous maps; and 3) performing change detection to assess the effectiveness of aquatic plant control efforts by comparing the before and after maps of water hyacinth cover. Two types of commonly available multispectral remotely sensed data are being used for mapping and change detection.

An IKONOS image was acquired for July 19, 2001 prior to field sampling and plant control operations (Figure 3). A second IKONOS multispectral image will be acquired approximately 6 months following plant control efforts. Researchers at the USDA ARS Subtropical Agricultural Research Center in Weslaco acquired 3-band, 1 m airborne natural-color video imagery of the river in July 2001 (Figure 4). Still images were frame-grabbed from the video tape and imported into the ERDAS image processing software. Field data were collected on the water hyacinth plant infestation on the Rio Grande River near Brownsville, TX in August 2001 for ground-truthing and to develop regression equations predicting water hyacinth cover, biomass, and height. At a series of sample sites, measurements were taken using a hand-held spectroradiometer. Biophysical data were collected at each site: plant mean height, above water green biomass, below water biomass, number of plants per quadrat, and visual estimates of percent cover. Location was recorded using GPS.

Figure 3. Ikonos image of water hyacinth blockages on the Rio Grande River, Texas, 19 July 2001.

Correlations between plant cover and spectral reflectance data were calculated. The models will be applied to the imagery to produce maps of water hyacinth cover. Thematic maps of water hyacinth were generated by an unsupervised classification of the IKONOS imagery. Prior to classification, a water mask was created to eliminate non-river parts of the Ikonos image, by classifying USGS color digital ortho quarter-quads. Water hyacinth and hydrilla classes were identified on the masked and classified IKONOS image using the field data.

Satellite data will be acquired about six months after the initial multispectral acquisition, for change detection. Two change detection techniques will be tested for assessing changes in aquatic plant cover: a post-classification comparison of the thematic maps of plant cover and; and image differencing to compute increase or decrease in plant cover using the before and

Figure 4. Airborne video image of water hyacinth mats on the Rio Grande River, Texas, 24 July 2001.

after maps created by using the regression approach. The final project goal will be to evaluate the cost-effectiveness of each data set and analysis technique, to estimate the total costs associated with each approach.

Credits: Investigators: Mark E. Jakubauskas, TerraMetrics, Inc and KARS program; Dana L. Peterson, KARS Program; Scott W. Campbell, Kansas Biological Survey, University of Kansas; Sam D. Campbell, TerraMetrics, Inc; David Penny, AquaSolutions; Frank deNoyelles, Jr., Kansas Biological Survey, University of Kansas;
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Airborne Data Collection Systems (ADAS) Application for Remote Sensing

An unmanned Airborne Data Acquisition System (ADAS) is being used for traffic surveillance, monitoring, and management (Figure 1). This lightweight system can fly for more than two hours with a sensor payload of up to 20 lbs. The use of sensors aboard unmanned aircraft can augment tools currently available. ADAS is not only inexpensive, but requires only a two-person crew and can easily provide various reconnaissance and surveillance information, depending upon the mission need.

ADAS has multiple interchangeable sensor packages to support diverse applications. Some examples of these sensors include day and night real time video, various types of multispectral and hyperspectral imagery, thermal infrared imagery, synthetic aperture radar imagery, moving target indicator radar, laser scanners, and even chemical, biological and radiological sensors. The system provides the users with high-resolution imagery that is georeferenced and overlaid with information relevant to the specific application. These sensors are low cost, lightweight solutions for surveillance needs.

GeoData Systems (GDS) is developing ADAS in a government and a commercial version. The government version has a larger/longer wing with integral fuel tanks, enabling the system to carry a heavier payload (fuel or sensors) and can fly higher. The system also carries government-unique communications allowing for a greater range.

The ADAS is comprised of three primary components: an aircraft, a sensor pod, and a ground station. All ADAS components are shippable 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 (Figure 2). Once the system is unpacked, it takes less than 30 minutes to set up. The

Figure 1. ADAS.

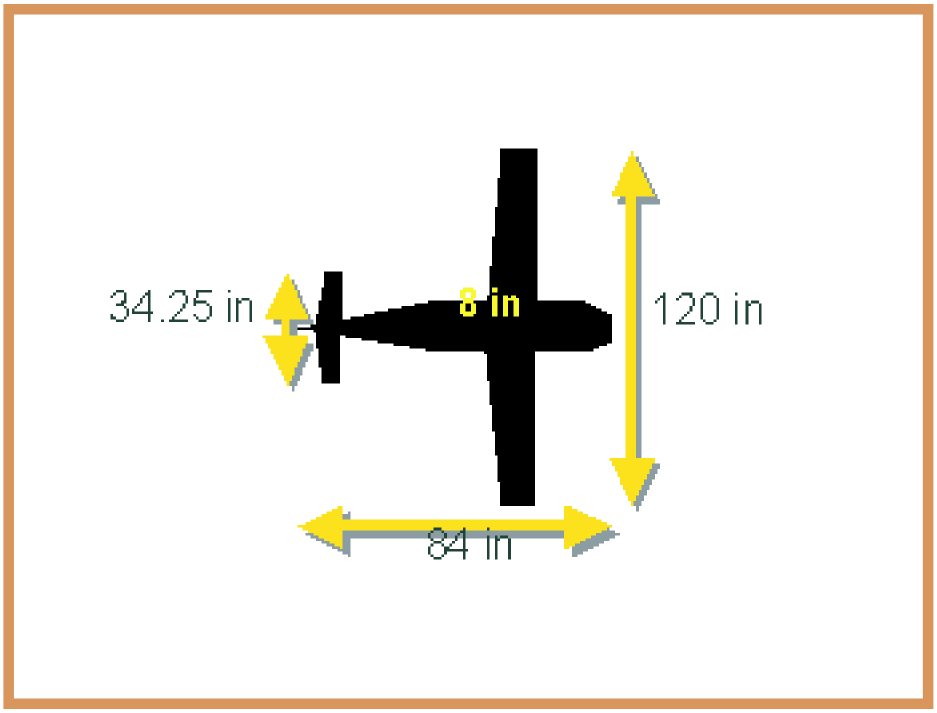

Figure 2. Size dimensions of ADAS.

ADAS aircraft and ground system is specifically designed for easy use with minimal training.

GDS will compare this innovative data collection technique with conventional methods in terms of cost, accuracy and timeliness. Also, areas where ADAS can be applied effectively and efficiently will be determined. The imagery will enable collection of peak hour volumes per direction, vehicle classification counts, turning volume counts at intersections and interchanges, and vehicle speeds.

The ADAS system is currently in the prototype phase, but plans are in place to move to production in mid-year 2002. Developmental prototypes of the commercial version of ADAS have successfully flown on multiple occasions.

Investigators: Ernest Carroll, GeoData Systems, Inc., DBR & Associates.

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Safety, Hazards & Disasters

EARLY WARNING, ASSESSMENT, MITIGATION, CRITICAL INFRASTRUCTURE

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The **NCRST-Hazards** Consortium creates and transfers remote sensing technology rapidly from the drawing board to practice. The primary goal is to identify, develop, demonstrate, and deploy image-based, GIS-compatible solutions to safety and hazard issues facing transportation authorities—and hence the traveling public. Users include state DOTs, county, local, and municipal transportation agencies, emergency response providers, public safety officers, and appropriate US/DOT Administrations.

Prior to September 11, 2001, NCRST-H products concentrated on key lifeline safety and hazard issues like the disruption of state, local, and rural road networks; pipeline safety; mapping airport glide path obstruction surfaces; assessing road segments at risk from avalanche and rock slides; and, developing models for large-area evacuation. Since September 11, the consortium has modified these products to include protection of the nation's critical transportation infrastructure resulting from deliberate acts of destruction.

In March 2002, the consortium convened a blue-ribbon panel of transportation, security, public safety, and remote sensing experts to address the immediate needs for critical infrastructure protection. The report from this two-day workshop is available on http://www.trans-

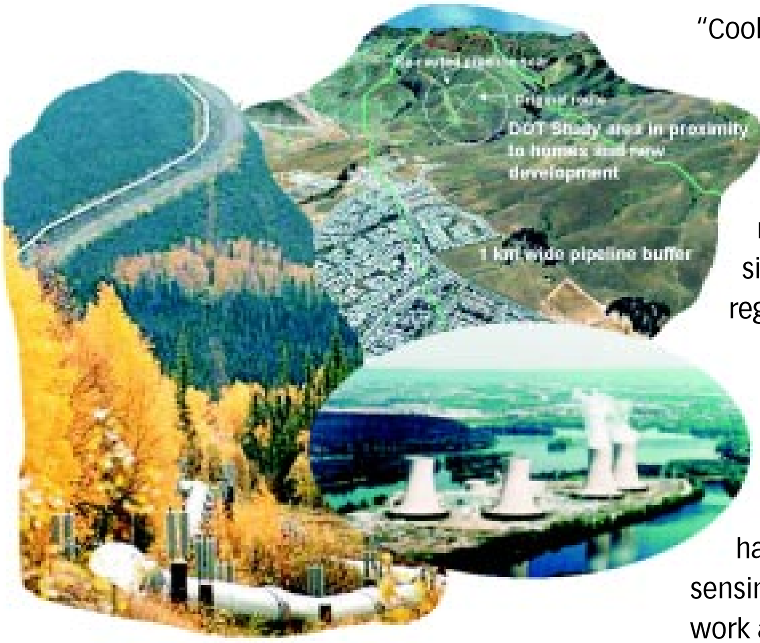

Figure 1. Critical infrastructure also includes pipelines and transportation grids around nuclear plants.

dash.org. A companion workshop is scheduled for early summer 2002 to begin inserting partial remote sensing products into these high priority needs.

NCRST-H products are designed for transportation planning communities from executive to engineering levels. Application Briefs, Technology Notes, White Papers, and Cookbooks have been published and are available on the NCRST-H website. The "briefs" are two-page documents designed to introduce transportation executives and program directors to the capabilities of remote sensing technologies. The "notes" are expanded versions of briefs, giving more detail to supervisors seeking remote sensing solutions to their mandated requirements. Many of these requirements are already partially addressed using existing geographic information system (GIS) solutions, so the question for remote sensing products is really one of return-on-investment (ROI) for cost and time.

The "white papers" are typically 10-page summaries of specific remote sensing technologies, written in the language of transportation engineers and planners. Each describes how the given technology works, its achievable accuracies, its typical costs, and a short list of back-up documents. A short list of commercial service providers is also included to "get started." "Cookbooks" are intended for technical staff to get "hands-on" experience with procedures to implement remote sensing solutions. BSN, Inc., a professional company with many years of experience with the transportation community, collaborates with the consortium to design and organize formal training products for regional and national workshops.

In the pages that follow, we report achievements from the first two years of our NCRST-H members, as well as from our Technology Application Partners (TAPs). The consortium has developed and is now deploying (1) a remote sensing toolkit for state, local, and rural road network applications, (2) products for protecting the national aviation infrastructure using LiDAR and aerial photography, (3) a report on workshops relating to remote sensing for critical infrastructure protection, (4) information about our industry/government collaborations and domestic/international outreach activities, and (5) our on-line searchable bibliographic database. The TAPs have concentrated their products mainly on pipeline safety and risk assessment, and on monitoring earthquake damage to transportation infrastructure using times series SAR data. We look forward to initiating dialogue or developing project activities with interested organizations in either the planning or service provider communities.

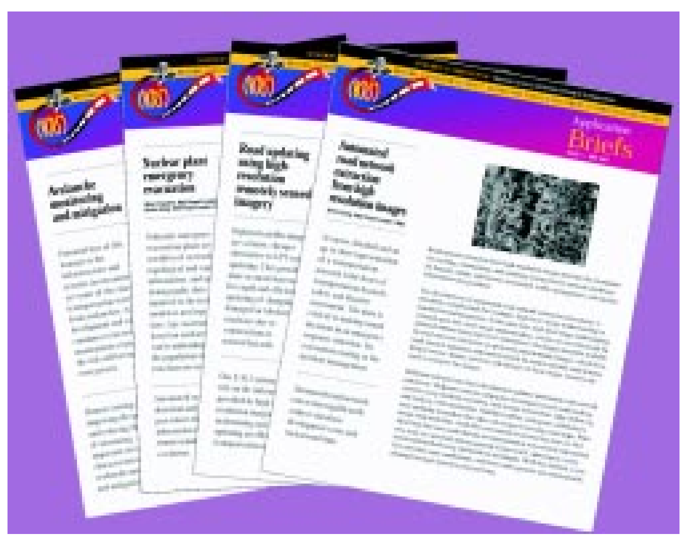

Figure 2. Sample "briefs" describe remote sensing applications for lifeline safety and hazards.

Synoptic, wide area, time sequential data acquired by remote aerial and satellite sensors offer a range of economical and efficient solutions to many mandated road network requirements. Data from imaging and non-imaging sensors serve as accurate, geospatial input for pre-disaster model scenarios, lifeline vulnerability assessments,

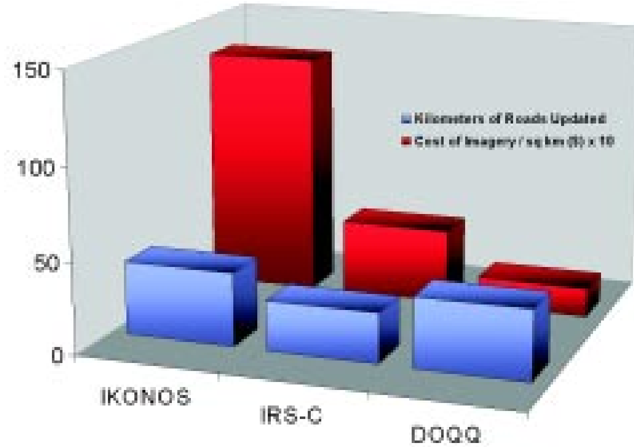

Figure 2. Comparative costs and efficiencies for road updates using high resolution imagery and human interpreters.

State, Local, and Rural Road Toolkit

evacuation planning, early warning of severe weather events, post disaster mitigation, emergency response, allocation of road maintenance assets, and many other applications. NCRST-H has developed an Internet accessible product that addresses specific requirements of transportation and public safety planners for assessing state, local, and rural road networks.

	Sub 1 Meter	1 Meter	10 Meter
Linear Network Elements			
Road Alignment	+	+	–
Number of Lanes	+	-	-
Intersection Type	+	-	-
Turn Prohibitions	+	–	-
Grade Separations	+	–	-
Historical Change	+	+	+
Related Polygonal Elements			
Traffic Zone Boundaries	+	+	–
Transit Barriers	+	+	–
Land Use and Coverage			
Development	+	+	–
Land Use Types	+	–	-
Location of Employers	+	+	–
Historical Change	+	~	~

Symbol Key: + Most useful – Somewhat useful - Not Useful

Figure 1. Image resolution and potential uses. Courtesy San Diego Association of Governments.

Working with NCRST-H, the Center for Transportation Analysis at ORNL has developed an image-based approach to automatic road extraction. Maps and high-resolution imagery are "matched" digitally to inventory known roads. Image attributes such as image tone, changes in tone, and neighborhood connectivity are developed to identify possible new road segments. To correct for errors of omission and commission, a dynamic programming algorithm is used to refine the network and to create road "candidates." Tests show the method generates acceptable results with good computational performance.

Accurate representation of road networks has always been important, but since September 11, 2001, we demand higher accuracy and currency for critical infrastructure protection. The Earth Data Analysis Center at UNM has compared costs and accuracies for human interpretation of high-resolution imagery. While automated systems are the technology of the future, human interpreters still out-perform computers for road updating. With sub-meter resolution from satellite sensors, repetitive map updates are feasible for such uses as emergency response, assessing lifeline vulnerability, and alternative routing for mass evacuations.

Many roads in Western America are unimproved. While not heavily trafficked, they are vital to the populations they serve, and are vulnerable to washouts from flooding, erosion, and snow accumulation. George Washington University, along with the Hopi Department of Natural Resources, McKinley Co., NM, and EDAC have developed aproduct for categorizing risk factors on rural roads. This nearly real-time information is vital for school bus scheduling, emergency service providers, deliveries, and maintenance vehicles. Combined with geospatial databases, knowledge from imagery; and the Weather Service allow better allocation of limited and dispersed road maintenance resources.

Slides are a common hazard and safety factor along mountainous roads. The University of Utah Geography Department has developed a product for identifying segments in Little Cottonwood Canyon, UT having higher risk of avalanche than adjoining segments. The product uses digital satellite imagery to delineate watersheds and locations of past slides. Vegetation and bare surfaces are mapped and a variable-shaped neighborhood is passed along the line to assign a risk value for each segment. Runout zones are then calculated and used to map stretches with variable degrees of risk.

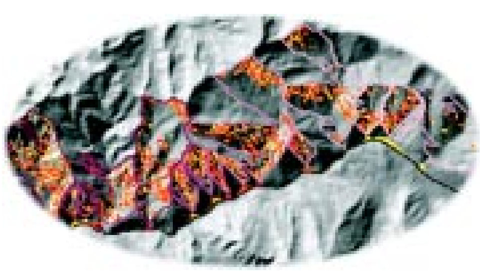

Figure 3. Sample basin runout zones and degrees of road risk.

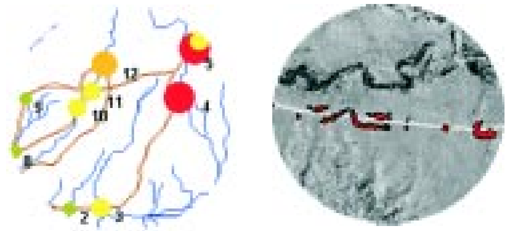

Figure 5. Road segments and their comparative risks for flooding, McKinley County, NM.

Using INSAR technology, methods have been developed to identify zones where roads, railroads, and pipelines are at risk from regional land subsidence.

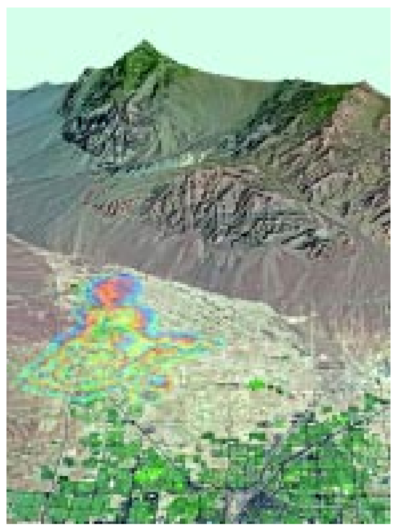

Figure 4. Subsidence zone near Las Vegas, NV. Developed by NPA Group, Kent, UK and published in Professional Surveyor.

Creation of a road mileage calculator was co-sponsored by the New Mexico State Highway and Transportation Department, whose purpose was to develop a consistent and accurate, FHWY-compliant, product for measuring road miles, county-by-county, on an annual basis. Combined with E-911 information, lifeline risk factors, current and cumulative weather radar data, and related resource allocations, more robust planning and emergency response efforts are possible.

ORNL has developed an emergency evacuation product (OREMS) that constantly monitors traffic networks, identifies changes in road geometry and traffic capacities, and records road repair bottlenecks to determine optimum steps for evacuating large populations quickly. The model has been tested using a hypothetical nuclear power plant emergency in Hamilton County, TN. One model run showed 90% evacuation in fewer than three hours.

The State, Local, and Rural Road Toolkit is available at http://www.trans-dash-org. It is a work-in-progress. Sample data sets and step-wise procedures for data processing will be included.

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Protecting the National Aviation Infrastructure

Providing safety and protection to the national aviation infrastructure has never been more important. Commercial and civil aviation and air transport are critical to the national security and economy. Protecting and managing increasingly crowded facilities and airspace requires complex 3-D information about the spatial relationships of airport environments. Remote sensing technologies are contributing cost-effective solutions for these requirements, as well as for the safety of the adjacent airspace. Both FAA and NIMA are creating standards for inflight and ground safety measures that must be met by all airport managers.

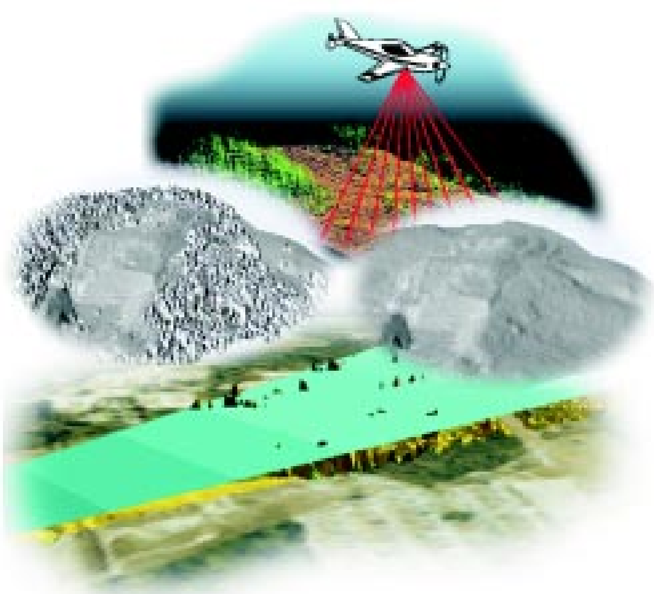

Figure 1. LiDAR system operations and typical output.

LiDAR, high-resolution satellite, and airborne imagery provide current spatial information on airport facilities and help to identify obstructions in the surrounding airspace. These technologies enhance airfield protection, security, and safety by allowing airport managers to visualize a broad range of spatial information in three dimensions to meet evolving federal standards.

In fall and winter 2001, NCRST-H, collaborating with Airborne 1, The Keith Companies, BAE Systems, Bohannan Huston, Inc., and I. K. Curtis, collected data to evaluate the capability and cost effectiveness of LiDAR and airborne imagery to identify objects protruding through the Obstruction Identification Surface (OIS). The OIS is a complex plane defined by NIMA and FAA which is used to recognize these obstructions. The team collected airborne LiDAR data with 1-meter spacing, and high-resolution aerial photography scanned at 45-cm spatial resolution. They also collected ground-based survey control and GPS data to spatially reference the project, and will use BAE Systems' Clear Flite software for data analysis and visualization. The project, called the Airfield Initiative Remote Sensing Technologies Evaluation Project (AIRSTEP), is currently evaluating the data

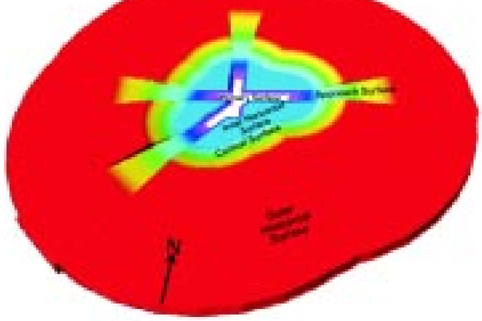

Figure 2. Glide path obstruction identification surface – Albuquerque International Sunport.

types to compare the costs and accuracies of each in accordance with FAA and NIMA requirements. The illustrations included here are courtesy of a companion project completed under NASA-sponsorship for the Albuquerque International Sunport. These LiDAR data were collected at 3-meter spacings, a coarser resolution than is normally used for evaluating airfield obstructions. Even at this coarser resolution, however, they show the range of obstruction identification and infrastructure mapping, possible using LiDAR.

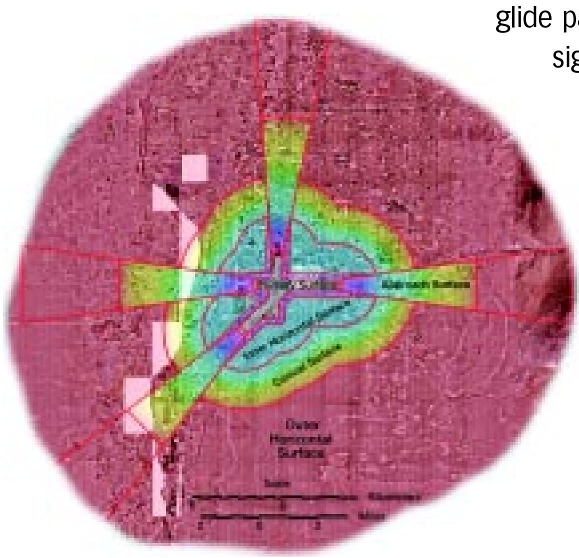

Figure 3. Albuquerque International Sunport with overlay of the obstruction identification surface.

Meeting FAA and NIMA standards for glide path obstructions is a significant challenge to airport administrators. To assist in meeting these standards, AIRSTEP outlines procedures and data requirements that are compliant with these standards. The product includes:

- Procedural outline for airfield obstruction identification
- Description of data requirements for airfield obstruction identification
- Assessing LiDAR and aerial photography for obstruction identification
- Assessing relative costs of LiDAR and aerial photography for obstruction identification

Remote sensing technologies are not limited just to identifying glide path obstructions. Other significant contributions lie in products for airport infrastructure mapping, visualization, and local terrain modeling.

The AIRSTEP product addresses these issues by providing online examples, references, and outlines for:

- Evaluating remotely sensed data for airfield infrastructure mapping
- Assessing flight path/ approaches using re motely sensed data
- Using three-dimensional visualization for assess ing airfield safety and security.

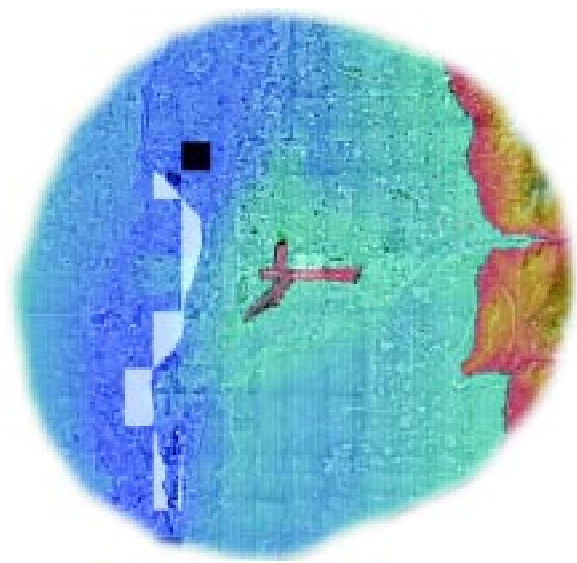

Figure 4. Image mosaic of Albuquerque International Sunport showing elevation gradient.

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Critical Infrastructure Protection
Through Remote Sensing and GIS Applications

"While roughly 20 percent of all incidents of international terrorism involve fatalities, the proportion of attacks on surface transportation systems involving fatalities is significantly higher. About two-thirds of the attacks on surface transportation have been intended to kill, and about 37 percent of the total involve fatalities. Brian Michael Jenkins, Protecting Public Surface Transportation Against Terrorism and Serious Crime: An Executive Overview, MTI Report 01-14, October 2001."

Figure 1. Vulnerable elements of the infrastructure.

Protecting the nation's transportation infrastructure against terrorist attacks has become a top priority, and will be an evolving industry as advanced technology enables more sophisticated, real-time, continuous monitoring. In-situ sensing systems have garnered the initial limelight for many CIP needs, but aerial and satellite sensors also offer significant prospects for enhancing synoptic views and time series information about transportation networks. Uninhabited aerial vehicles (UAV's) equipped with imaging and non-imaging sensors have the ability to monitor traffic flows, survey individual vehicles at intermodal facilities, track suspicious vehicle movements, and even to detect minute concentrations of chemical and biological materials. Many existing products of remote sensing for transportation safety, hazards, and disasters can be adapted to CIP by rethinking the data collection requirements and customizing the temporal, radiometric, spectral, and temporal resolution of candidate sensors to fit these requirements. Among the

Figure 2. IKONOS "before and after" images of World Trade Center. Satellite images by Space Imaging.

Figure 3. Airborne digital camera image of WTC September 15, 2001.

Figure 4. Airborne digital camera image of WTC September 17, 2001.

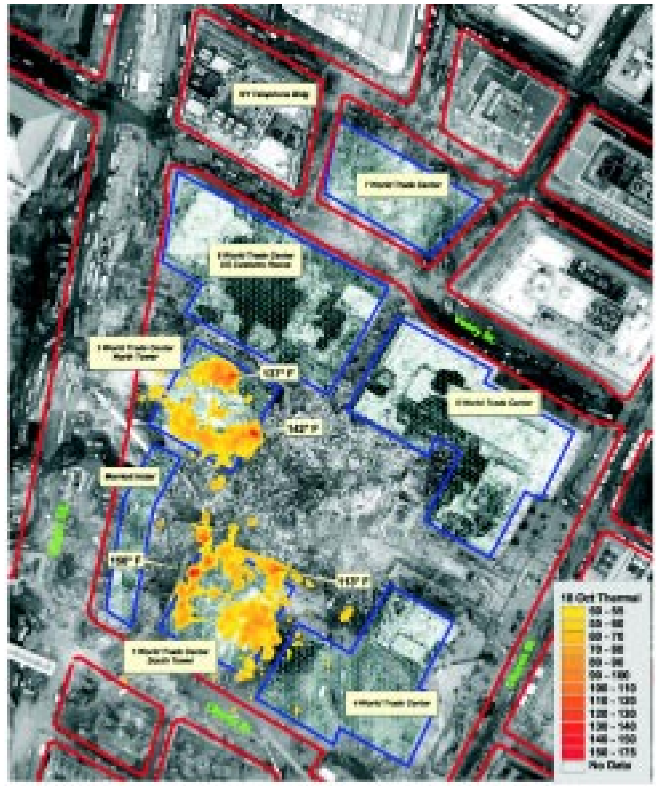

Figure 5. Image courtesy of EarthData. The image shows thermal data that were collected over the World Trade Center on October 18, 2001, with the FLIR Thermacam SC2000. Areas that register above 50 degrees Fahrenheit are overlain onto orthophotos generated from digital photography collected on October 7, 2001 with a Kodak Megaplus 16.8i camera. The building footprints and curb information are from the New York City Landbase and are depicted in blue and red respectively.

current products that are adaptable for CIP needs are:

- Techniques for Assessing Risk of Slides and Slide Mitigation
- Wide-area Evacuation Planning
- Pipeline Monitoring for Leaks and Risk Analysis for Explosions
- Airport Glide Path Obstruction Detection, Airport Security, and Aircraft Interdiction
- Chemical monitoring of truck, rail, and intermodal transport systems.

Several of these products are already available from NCRST-H.

In November 2001, NCRST-H conceived a plan for bringing together transportation administrators in planning, security, public-safety, and remote sensing. The breadth of needs for improved transportation security, however, and the wide variety of transportation modes suggested that a single workshop would only scratch the veneer in providing a blueprint for action. The consortium's first workshop, held in March 2002, explored the range of transportation security needs and provided a rationale for subsequent workshops more narrowly focused on specific modes and technologies. The aim was to address CIP needs from a modal perspective, and to identify the unique data collection, processing, and information dissemination systems required for deploying adaptable detection and surveillance technology.

The product from the first workshop is available at http://www.trans-dash.org.

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Industry/Government Collaborations and Outreach

The intent of NCRST-H is to develop and deploy remote sensing technology rapidly for transportation safety, hazards, and disasters. The best way to accomplish this is to team with industry and government partners to match needs with technologies, and to pool financial resources. In its first two years, the consortium has teamed successfully with numerous organizations to identify needs and to then collect, process, and apply aerial and satellite data to demonstrate new and more efficient ways to address those traditional, often mandated, needs.

Outreach is a companion to collaboration. With results of demonstrations in hand, the consortium is able to broaden its reach to all user communities having similar requirements. This has been accomplished in several ways: (1) by exhibiting at national and regional meetings, (2) by distributing electronic and hard-copy products, (3) by contracting with professional organizations to convert technology into viable training products, (4) by direct office-to-office and face-to-face exchanges to explore adoption of new technology, and (5) by organizing and conducting workshops, seminars, and technical briefings.

Within the U.S., the consortium has initiated dialogue with, and in some cases has already completed activities with, state DOTs (NM, WA), Municipalities (Santa Barbara, San Diego), Counties (McKinley Co, NM; Maricopa Co, AZ, Hamilton Co., TN; Salt Lake Co., UT), Indian Reservations (Hopi, Pueblo of Isleta), and federal transportation administrations (FAA, FMCSA, FHWA, and BTS). Aside from the Technology Application Partners (AERIS, DigitalGlobe, and Image Cat) these activities have included many Commercial firms, among them Space Imaging, EarthData, BAE Systems, Airborne-1, Bohannan Huston, Spencer B. Gross, The Keith Companies, I.K. Curtis, BSN, Leica Geosystems, LH Systems, The Outsource Ltd., LaSen, and Psomas.

In 2001, the consortium inaugurated an international outreach effort aimed at introducing the broader community of transportation planners to new remote sensing applications. The desire is not only to transfer the tech-

Figure 1. FMCSA employee discussing NCRST-H activities at 2001 Congressional Showcase.

nology, but also to provide commercial opportunities for American business. In October and November delegations were sent to Europe and People's Republic of China to establish contact and survey levels of interest in collaborative projects, joint conferences, resource sharing, and technical exchanges. In early April 2002, delegations from both China and NCRST met at the East-West Center in Honolulu to develop and coordinate plans for joint efforts in 2002 and beyond. Among the first efforts will be an NCRST-wide technology buffet at the International Society for Remote Sensing and Photogrammetry (ISPRS) symposium in Xi'an, China. The Buffet is titled Geospatial Systems for Transportation-related Applications. Among others, participants include: EarthData, Inc., NASA Goddard Space Flight Center, Earth Data Analysis Center, Intermap Technologies Corp., and George Mason University.

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CAB:
An Online Resource for Remote Sensing Applications in Transportation

Remote sensing technology has matured since the early 1970s when Landsat-1 was launched. Early applications included agricultural monitoring, natural resource management, mineral exploration, and urban planning. Products for transportation planning, monitoring, and mitigation have emerged in the 1990s as mostly academic pursuits and have only lately been entertained seriously by practicing professionals in transportation agencies. A wealth of information and experience gathered by users of remote sensing technology since the 1970s has been recorded in technical articles, conference proceedings, books, manuscripts, reports, and websites that could be beneficial to the transportation community. NCRST-H has a product called the Citations and Annotated Bibliography (CAB) Database to lead users into the literature on remote sensing for land transportation. The primary focus of this online, interactive product is on references related to remote sensing applications in safety, hazards, and disaster assessments for transportation lifelines. Aside from practicing professionals, the CAB is also a guide to research and development organizations looking for ways to improve the state-of-the-art for technology; and to NCRST-H, itself, as a way to identify technology that is maturing toward deployment if it can be demonstrated to be cost effective and accurate.

The database includes relevant citations in fields related to natural hazards, transportation, and geospatial technologies. Many citations were collected electronically from other online, distributed databases. Using keywords, keyword pairs, and Boolean operators, pertinent references were extracted from these sources, edited, and entered into the database. CAB also contains references obtained from a partially annotated database developed by the Department of Geography at Southwest Texas State University, and from other researchers.

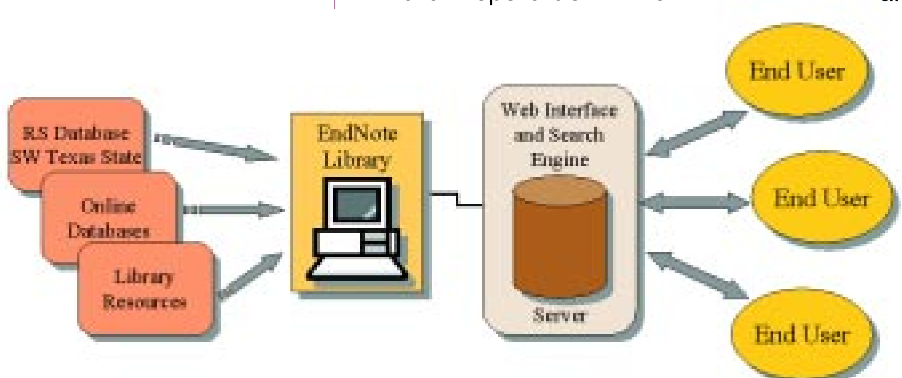

Figure 1. Database architecture.

The database is a work in progress and is constantly evolving. Currently, it contains references to more than 2000 journal articles, proceedings, books, reports, and other sources. Referenced journals range from those focusing on remote sensing research and applications to those emphasizing transportation applications. About 25 percent of the citations reference some mode of transportation, primarily roads and highways. Pipelines constitute the smallest set of references. When considering geospatial analytical tools for transportation, about 60 percent of the transportation citations reference remote sensing, 40 percent for GIS, and 20 percent for GPS. The database also includes citations on environmental factors that can impact transportation analysis, planning, and construction.

CAB emphasizes the needs of NCRST-H, therefore it tends to include entries related to the consortium's specific interests in various kinds of slides (e.g., rock, avalanche, mud), subsidence, earthquakes, trafficability, emergency response, and (now) critical infrastructure protection. It is not intended to meet the needs of all users of geospatial technologies and transportation data. As the database evolves, it will broaden its scope to include interest areas of the other NCRST consortia.

The database is designed for general use and can be accessed via the NCRST-H website at http://www.trans-dash.org. The search window contains three fields (author/editor, title, and year) in which keywords, combinations of keywords, or any text can be entered to query the database. Citations matching the query are returned as a list, from which the user can select and download desired bibliographic references. Users can opt for one of three export formats: tab delimited text, Endnote export, or html.

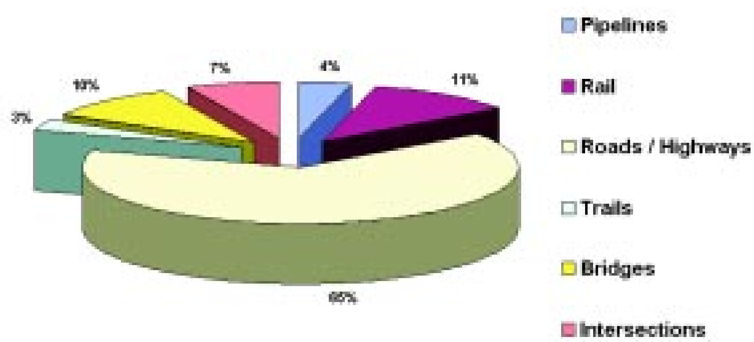

Figure 3. Transportation modes as percentage of total citations referencing transportation.

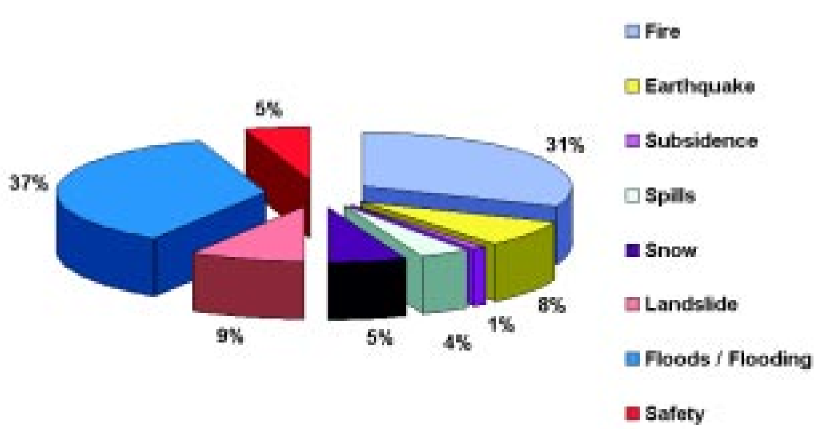

Figure 2. Percentage of citations referencing safety, hazards, and natural disasters.

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Post-Disaster Bridge Assessment

In extreme events such as earthquakes, the performance of highway bridges is a major concern. Serious damage to these components can have far-reaching implications, including the impedance of critical emergency response actions. Furthermore, failure to detect collapsed bridge spans, particularly during the first few minutes of an earthquake, often results in serious injuries and fatalities.

The main goal of this project is to develop innovative methods for near real-time highway bridge damage assessment, employing remote sensing technology. The first phase of the study, with which this report is concerned, focuses on data collection and processing, demonstrating how spatially and temporally diverse data sources can be efficiently integrated and processed. Our goal in these early tasks is to demonstrate that these techniques can be integrated efficiently and that their application extends well beyond the earthquake problem, i.e. general urban monitoring.

New techniques have been developed by project team members to analyze datasets. For data visualization, the tool *Bridge Hunter*, developed by the project team, has proved to be particu-

Sample output from Bridge Hunter

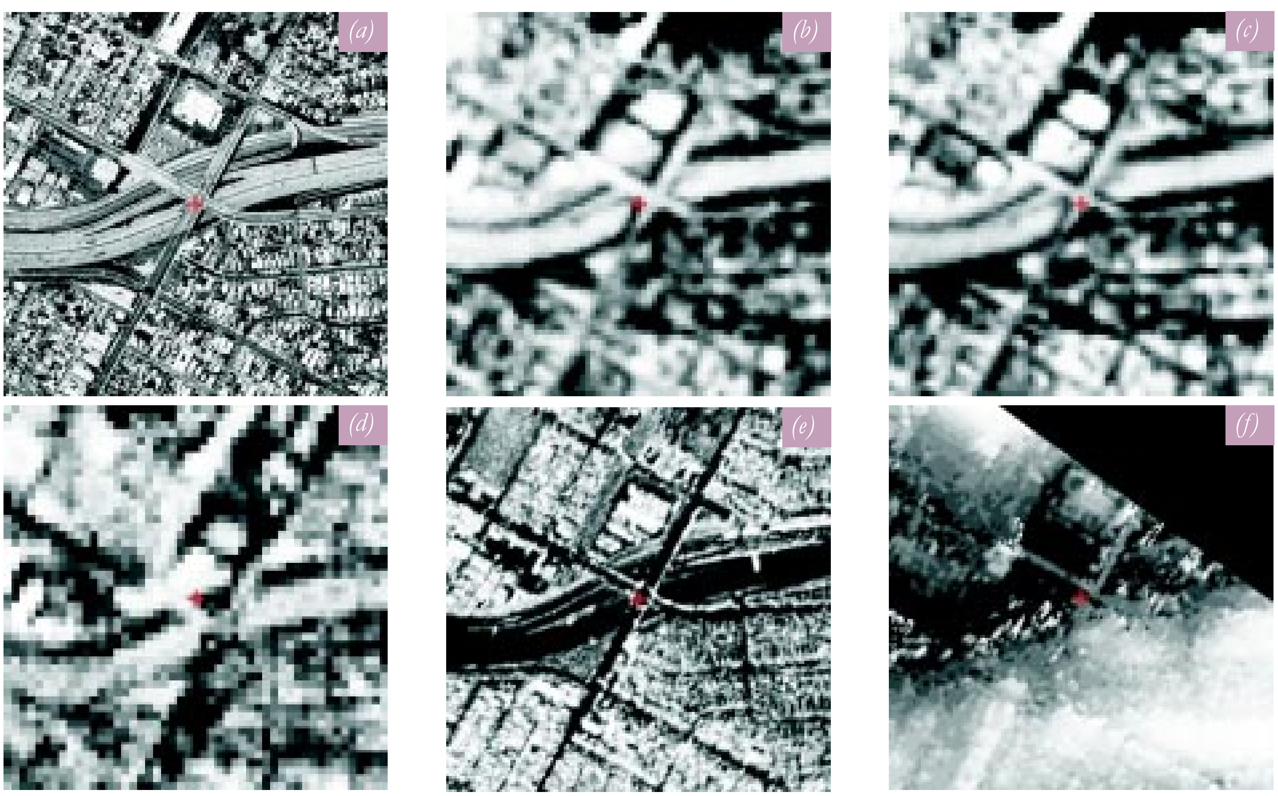

Figure 1. Images located by Bridge Hunter (Bridge: 530133; Location: Santa Monica; Damage: minor)

Data	Data Acquired	Resolution
a) Panchromatic aerial photograph	5/31/94	1m
b) Panchromatic SPOT image	9/11/93	10m
c) Panchromatic SPOT image	1/20/94	10m
d) Panchromatic Landsat 7 image	9/20/99	15m
e) Aerial SAR intensity image	1997	2.5m
f) Aerial SAR interferometric DEM	1997	2.5m

Table 1. Description of images in Figure 1.

larly effective. This customized software integrates remote sensing imagery and federally managed databases on U.S. highways and bridges. The end product of Bridge Hunter is a versatile catalogue of key bridge attributes and images from a full range of airborne and satellite sensors captured before and after an event. These include: commercially available airborne and space borne optical sensors; synthetic aperture radar (SAR) sensors; LIDAR (or laser technology); and GPS field sensors. Bridge Hunter also employs intelligent database and data management programs, customized image processing techniques and high-end computational batch processing systems. Examples of the resulting output are included at the end of this report.

Bridge Hunter employs a three-stage processing sequence:
(1) Federal databases are analyzed to locate individual bridges on the highway network through dynamic segmentation
(2) An extension to the image processing software locates and extracts images from all available imagery and performs image enhancement functions.
(3) The imagery is catalogued in a single, user-friendly spreadsheet for printing and examination. All imagery is presented at the same scale.

First, databases from the National Highway Planning Network (NHPN) and the Highway Performance Monitoring Systems (HPMS) are analyzed and merged. Using Linear Reference System (LRS) data, information is extracted for the transportation network. The National Bridge Inventory (NBI) database provides bridge data concerning: location; size; type; observed damage states; and damage modes. As a result, individual bridges can be identified, characterized and their respective positions extracted.

Second, an automated computer batch-processing algorithm is run on each remotely sensed image (including LandSat7, SPOT, JERS, SAR, aerial SAR, aerial panchromatic photos). All images are georeferenced to a standard map projection. Raw SAR images are pre-processed, using their satellite parameters, and similarly co-registered. Lastly, to enhance the quality of output, image processing routines are executed.

The development of Bridge Hunter is an important step in the creation of damage algorithms. Providing a complete, before and after visualization of the damaged, and undamaged bridges in a variety of bands and with a variety of sensors provides the ability to assess where damage is visible. Additional attribute information from the NBI database and observed damage from Northridge is also integrated for reference. The next step will focus on the process of automatically detecting the changes visible in the catalogue.

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REMOTE SENSING AND SPATIAL INFORMATION TECHNOLOGIES APPLICATION TO MULTIMODAL TRANSPORTATION

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