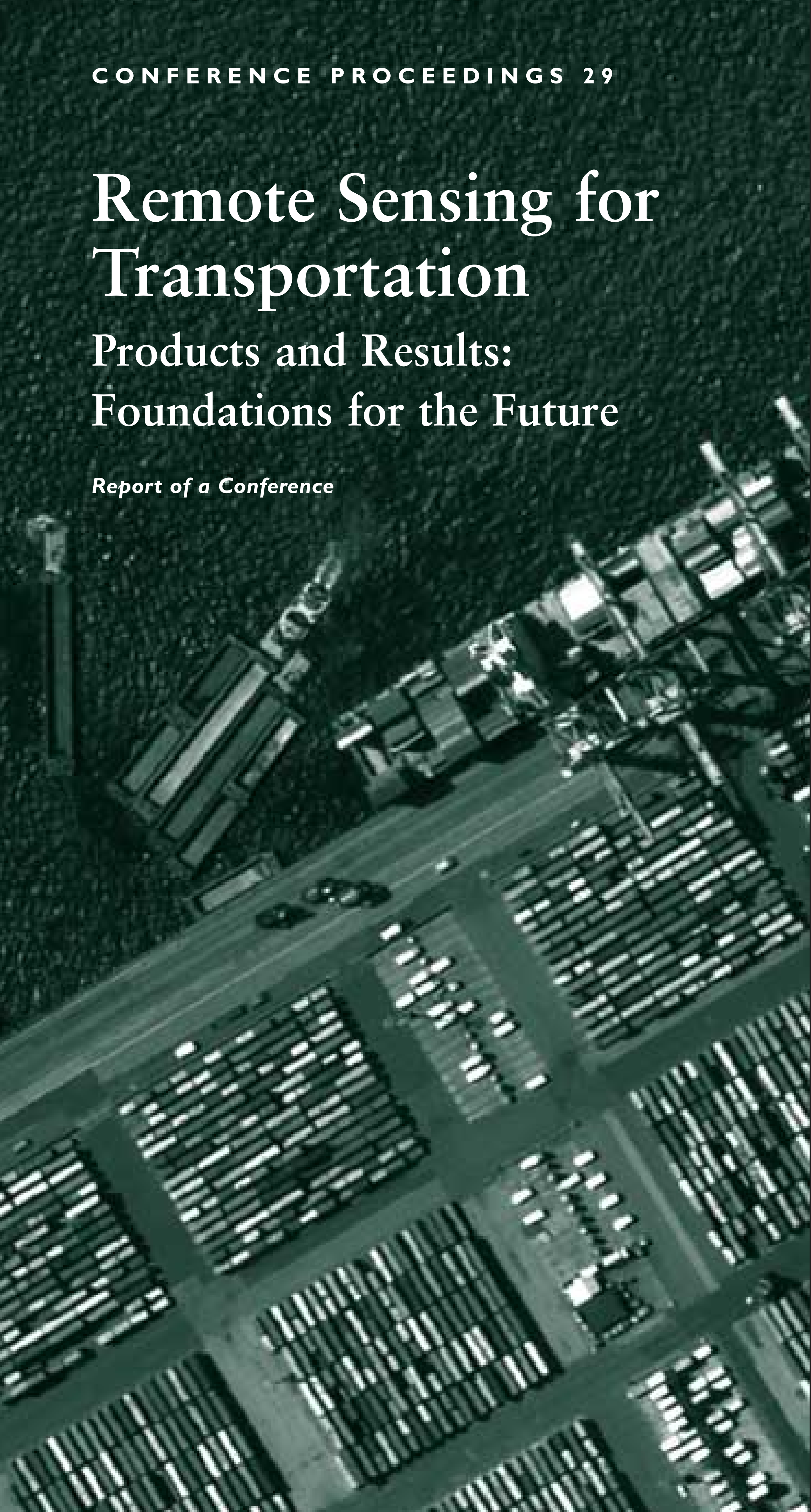
CONFERENCE PROCEEDINGS 29

# Remote Sensing for Transportation

## Products and Results: Foundations for the Future

*Report of a Conference*



TRANSPORTATION RESEARCH BOARD
*OF THE NATIONAL ACADEMIES*

CONFERENCE PROCEEDINGS 29

# Remote Sensing for Transportation

## Products and Results: Foundations for the Future

*Report of a Conference*

**Committee for Conferences on Remote Sensing and Spatial Information Technologies for Transportation**

Washington, D.C.
December 10–12, 2001

*Sponsored by*
Research and Special Programs Administration,
U.S. Department of Transportation
National Aeronautics and Space Administration
Transportation Research Board

*Cosponsored by*
American Association of State Highway and Transportation Officials
National States Geographic Information Council

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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*Cover photo: Digital Globe*

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*Advisers to the Nation on Science, Engineering, and Medicine*

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# Contents

# Foreword

David S. Ekern, *Conference Committee Chair*

These proceedings summarize the highlights from the Conference on Remote Sensing for Transportation—Products and Results: Foundations for the Future. The conference was held December 10 through 12, 2001, at the National Academy of Sciences in Washington, D.C., as the second in a series of three on the subject of remote sensing in transportation. The first conference was held December 4 and 5, 2000, also in Washington, D.C.

This 2-day conference was organized by the Transportation Research Board and sponsored by the Research and Special Programs Administration of the U.S. Department of Transportation and by the National Aeronautics and Space Administration. The American Association of State Highway and Transportation Officials and the National States Geographic Information Council were cosponsors.

The conference brought together representatives from academia, transportation agencies, remote sensing businesses, consulting firms, and other groups. The core general sessions heard presentations from the four National Consortia on Remote Sensing in Transportation on the results of their research activities. Session moderators experienced in the transportation industry initiated discussions with conference participants on the impacts of these research activities. A Technology Buffet of displays on remote sensing gave participants the opportunity to visit with individual researchers. In the final session, eight transportation and remote sensing experts offered their assessments of the penetration by remote sensing technologies in the transportation industry and the usefulness of these applications. The conference was preceded by five workshops and a Roundtable for States and Metropolitan Planning Organizations, in which practitioners shared information on the uses of remote sensing in their organizations.

The objectives of this conference were

1. Enhancing communication between the transportation and remote sensing communities,
2. Developing a common understanding of current successful applications of remote sensing to transportation, and
3. Crafting strategies for implementation of remote sensing in transportation.

A number of people contributed to the success of the conference and deserve recognition. First, I would like to thank the other members of the conference committee for their time and effort in organizing the conference and guiding the preparation of this report. K. T. Thirumalai of the Research and Special Programs Administration at the U.S. Department of Transportation deserves special recognition for helping to develop the conference concept and obtaining federal support for the workshop and the conference. Transportation Research Board Senior Program Officer Thomas M. Palmerlee and his Program Assistant Fred N. Scharf of the Transportation Research Board did an outstanding job with conference logistics. Transportation Consultant Henry L. Peyrebrune prepared and assembled the report manuscript. Finally, I would like to thank all the participants for sharing their ideas, issues, and visions related to remote sensing applications in transportation.

The conference, which is the subject of this report, was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The conference committee members responsible for the report were chosen for their special competencies and for their representation of an appropriate balance. This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that assist the institution in making the published proceedings as sound as possible and to ensure that this report meets institutional standards for objectivity, evidence, and responsiveness to the charge. The review comments and draft manuscript remain confidential to protect the integrity of the process.

The committee thanks the following individuals for their review of this report: Robert J. Czerniak of New Mexico State University, Las Cruces; Jack H. Hansen of the University of Tennessee (Emeritus), Reno, Nevada; Kenneth S. Miller of the Massachusetts Highway Department, Boston; and David B. Zilkoski of the National Geodetic Survey, Silver Spring, Maryland.

Although the reviewers provided many constructive comments and suggestions, they did not see the final draft of the report before its release. The review of this report was overseen by Lester A. Hoel of the University of Virginia, Charlottesville. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Suzanne Schneider, Associate Executive Director of the Transportation Research Board, managed the report review process. The views expressed in the report's presentations, papers, and discussion summaries are those of the authors and do not necessarily reflect the views of the conference committee, the Transportation Research Board, the National Research Council, or the conference sponsors. Responsibility for the final content of these proceedings rests entirely with the conference committee and the institution.

# Introduction to the Proceedings

David S. Ekern, *Conference Chair*

Transportation agencies at all levels face unprecedented challenges today. Demands are increasing on these agencies to preserve the existing transportation system and to take on new missions. A variety of advanced technologies is available to enhance the planning, designing, managing, operating, and maintaining of all modes of transportation. Aerial and satellite remote sensing is one area that is experiencing rapid development. As John Jensen noted at the 2000 conference, "[R]emote sensing Earth observation from aircraft or satellite may be considered an information business. The goal of the business is to obtain earth resource information by measuring and examining electromagnetic radiation reflected or emitted from the Earth's surface . . . and supply the data or derived . . . information to users."

Collectively, the goals of the three conferences on remote sensing are to (1) develop awareness of remote sensing within the transportation community, (2) provide input from potential users, (3) showcase practical applications and uses of the tools and technologies, and (4) give direction for future transportation remote sensing program activities.

This conference was the second of the three conferences on remote sensing and spatial technologies, with the first being held 1 year ago. The conferences are an opportunity to track the progress of the National Consortium on Remote Sensing in Transportation (NCRST), which is in the second of a 4-year research program authorized in the Transportation Equity Act for the 21st Century (TEA21). NCRST was established in 1999 by the U.S. Department of Transportation (USDOT) in collaboration with the National Aeronautics and Space Administration (NASA) to focus on application of commercial remote sensing technologies to the transportation industry. Research is conducted through four university consortia. The lead universities and their subject matters are

- Mississippi State University on environmental impact assessment;
- University of California, Santa Barbara, on infrastructure management;
- Ohio State University, on regional traffic monitoring; and
- University of New Mexico, on safety hazards and disaster assessment.

The objectives of the first conference were to improve both the understanding of remote sensing among transportation professionals and the understanding of key transportation issues among remote sensing experts; and to facilitate the ongoing communication among all groups interested in remote sensing and transportation. The Steering Committee believed that the research program had advanced to the point that the theme for the second conference could be "Products and Results: Foundations for the Future." While the committee recognized that the consortia were only in Year 2 of a 4-year research cycle, it decided that the best way to advance the state of the practice was for the user community to see the products and applications—to see what is working, what is not yet working, and what is promising—and to learn about the barriers and opportunities that arise during implementation. The committee had three objectives:

1. Enhancing communications between the transportation and remote sensing communities,
2. Developing a common understanding of current successful remote sensing transportation applications, and
3. Crafting strategies for remote sensing implementation in transportation.

The Transportation Research Board (TRB) Committee organizing the conference was interested in attracting a broad mix of participants that would encompass both practitioners and users of remote sensing products, industry representatives, and the research community. More than 150 people attended the conference, and the desired mix was achieved with representation from state departments of transportation, metropolitan planning organizations (MPOs), local government, USDOT, other federal agencies, universities, the private sector, and other organizations. (See Appendix E, page 85, for the list of participants.)

## Progress Since the 2000 Conference

Significant progress has been made, but there is still a long way to go before the consideration of remote sensing technologies for collecting transportation information becomes routine.

One way to measure progress is to consider the eight themes developed from the 2000 conference and review the new issues that came before the 2001 conference. The 2001 status of the 2000 conference themes is presented below.

### Theme 1. Closing the Knowledge Gap Between the Remote Sensing and Transportation Communities

At the 2001 conference, it became clear that the knowledge gap is closing: the remote sensing community is gaining a better understanding of the highway planning and project development process. The 2001 Conference featured a Technology Buffet, where 37 different projects were displayed on the application of remote sensing technologies to transportation issues. (See Appendix C, page 80, for a complete list of projects and contact persons.) Through these projects and applications, the transportation community is beginning to understand the capabilities and limitations of remote sensing information. As technology changes and new transportation issues arise, the applications will expand to other modes and to intermodal and multimodal issues. The need for communication will be ongoing.

### Theme 2. Enhancing Ongoing Communication Among All Groups Interested in Remote Sensing Transportation Applications

At the 2001 conference, enhancing communication was considered a work in progress. Significant progress has been made among a small circle of users and providers. Many attendees at the 2001 conference also attended the 2000 conference. Four workshops at the 2001 conference provided an opportunity for sharing information in depth on several subjects. (See Appendix B, page 79, for a list of subjects and contact persons.) Relationships are developing between the remote sensing industry and the transportation community. The circle of contact needs to be expanded in future years.

### Theme 3. Expanding Workforce Development and Training

At the 2001 conference, workforce development and training continued to be recognized as a priority for the future. Little progress has been made in the past year, since concentration was focused on product and application development. The sense from the 2001 conference is that concentrating on expanding awareness of the potential of remote sensing is the initial priority.

### Theme 4. Enhancing Technology Transfer and Moving Research Findings and Products Quickly into Practice

At the 2001 conference, many of the presented products and applications are approaching the point of release for implementation. For more than half of the technology application projects for 2002, state departments of transportation are either the primary investigator or a partner in the application. The discussion in 2001 was how to package and market these products.

### Theme 5. Developing Standards

At the 2001 conference, the development of standards continued to be an issue, but the discussion has not advanced to the point of defining who should have responsibility for developing standards, which mechanisms are best, and which areas are priorities. Many felt that, at this time, it is more important to focus on identifying users rather than on establishing standards.

### Theme 6. Encouraging Innovative Partnerships

The 2001 conference highlighted several innovative partnerships that have been formed, including for technology application projects. In 2002, 18 technology application projects will involve 10 state departments of transportation along with other transportation and public agencies. (See the Proceedings for details on many of these applications.) Partnerships were also emphasized in the State Roundtable discussion (see Appendix A, page 65).

### Theme 7. Defining Specific Research Needs

Progress was reported at the 2001 conference in a number of areas for research, recommended as priorities at the 2000 conference. The 2001 conference identified additional tasks within the four topic areas and reinforced and redefined several areas previously recommended.

### Theme 8. Promoting Innovative Thinking

While the 2001 conference placed emphasis on products and applications, the issues raised at the 2000 conference continued to be in the background. The 2001 conference discussed the need to market products and applications, but work remains to be done on the concept of developing a strategic plan or approach.

## Themes Emerging from the 2001 Conference

Eight new headlines or themes on remote sensing for transportation emerged from the 2001 conference and are presented below.

**Theme 1. Transportation is not the major driver in the development of remote sensing technologies, but transportation can be a significant user of remote sensing information.**

The American Society for Photogrammetry and Remote Sensing is conducting a 10-year remote sensing industry forecast. This is the first comprehensive forecast prepared for this industry, and as such, it will be subject to revision and updating in the future. However, the forecast can be used to establish a relative scale of the transportation sector market for remote sensing. Results from the study's early phases show a $1.8 billion market for remote sensing in 2000 that will increase to $6.0 billion in 2010. Representing about 9% of the total market, transportation is forecast as the remote sensing industry's fourth largest market, increasing from $162 million in 2000 to $540 million by 2010. While this is a significant number, it is a small portion of the more than $100 billion that all levels of government are expected to spend on highways alone annually (1997). Remote sensing is a tool, an enabling technology. It is not a need, a program, or a stand-alone activity. Remote sensing is a complementary tool and is not in competition with other tools or programs.

**Theme 2. There are two types of applications for the use of remote sensing information:**
- **Doing current activities quicker, better, and more cheaply; and**
- **Expanding the ability of the transportation community to conduct new activities, consider additional factors, and improve current decision processes.**

Transportation agencies have a large investment in their current information systems, workforce, training, software, and hardware. To change current practices so that the use of remote sensing information is considered, the research program must be able to show that remote sensing helps speed the process, improves the quality of the product, and is cost-effective.

**Theme 3. Remote sensing information is rarely stand-alone information in the transportation sector.**

The applications to date show that remote sensing information must be combined with other information sources, either for calibration or control purposes or for gaining a complete picture. Thus, issues currently under study in other areas of the transportation research community—such as data integration, data sharing, and data fusion—are also relevant to remote sensing.

**Theme 4. To be successful, remote sensing information should be directly related to the transportation agency's decision support systems.**

Most transportation agencies have in place well-defined transportation decision support systems that are modified over time because of federal or state legislation or changing values and social conditions. Examples are systems for pavement management, bridge management, congestion management, asset management, and design manuals. These different decision systems comprise seven basic transportation agency functions:

- Long-range planning;
- Programming and budgeting;
- Project development, including design;
- Construction, including traffic and environmental mitigation;
- Maintenance, including routine, preventive, and emergency;

- Operations and management; and
- System security.

The current research program has touched on parts of most of these functions but has not yet examined the decision processes in detail for opportunities for remote sensing technology.

**Theme 5. Application of remote sensing technologies to all modes and to intermodal and multimodal issues is just beginning.**

Most applications presented at the 2001 conference applied to highway issues. The application of remote sensing to the other passenger modes—transit, aviation, rail, water-borne, pedestrian, and bicycle—and to freight transportation is still very sketchy. The implications of remote sensing information for intermodal and multimodal planning and development need to be pursued.

**Theme 6. Transportation agencies' current state of the practice in information technology involves geographic information systems (GIS), the Global Positioning System (GPS), and digital orthophotography.**

The technology environment for the introduction of remote sensing varies greatly in transportation organizations. At the point that it is considering introducing remote sensing information, each transportation agency is starting from a different "technology environment"—its information technology capability, GIS, GPS, fiber optics, technology awareness, software, and hardware. Since introducing remote sensing requires a fairly well-developed technology environment, a first step for a state agency that is considering use of remote sensing information is assessing its technical capability to handle and use such information. During the state roundtable discussion, only 1 of 15 participating states reported that it had incorporated the consideration of remote sensing information into its routine business.

**Theme 7. The remote sensing effort can learn from past efforts to introduce technology into transportation processes.**

The introduction of remote sensing is analogous to the introduction of GIS and intelligent transportation systems (ITS) technology to transportation decision processes. The lessons learned from these activities can be carried over to remote sensing. Three key lessons were: (1) it takes time to introduce new technologies into an already highly developed decision process, (2) experimentation with real-world applications is a strategy for success, and (3) the new technology must be directly tied to the decision support systems.

**Theme 8. As transportation agencies reexamine processes for project development and the approval process, the availability of remote sensing information may provide an opportunity for changing the standards for information and data from those based on old methodologies of data collection and analysis.**

Many data accuracy standards have been in place for a long time. They are based on ground data acquisition methods and on a project development process in which decisions are made late in the process during the detailed design phase. Currently transportation agencies are reexamining the project development processes to speed up project delivery, including environmental streamlining, and to make some project decisions earlier in the process during the planning phase. Remote sensing offers the opportunity to reexamine the questions of "What do we need to know, at what point in the decision process, and at what level of accuracy?" The use of image analysis and other remotely acquired data may allow certain decisions—such as environmental impacts, utility location, and right-of-way requirements—to be made earlier in the process when the degree of accuracy is not as stringent as that needed for final design plans.

## Assessment: Where the Initiative Stands

The final session of the 2001 conference gave numbers of panelists the opportunity to comment on the status of the initiative to date: its strengths, weaknesses, opportunities, and threats. This strategic assessment, summarized below, also incorporates participation from others at the conference.

### Strengths

The major strengths of remote sensing information for transportation are

- Collecting remote sensing information is nonintrusive. Transportation agencies are always looking for ways to improve employee safety and to minimize the amount of time employees spend on the roadway dodging traffic.
- Information gathering is potentially quicker, cheaper, and better with remote sensing.
- Remote sensing provides access to places that are impossible or too expensive to reach with other methods and provides a synoptic view.
- The technology delivers the ability to collect continuous information at a low cost.
- Accuracy is improving (spatial and spectral) in remote sensing as its cost is decreasing.

- The definition of remote sensing is changing to include technologies better suited for transportation, such as uninhabited aerial vehicles (UAVs) and pole-mounted video systems.
- Instrumentation of the national highway system. (Only 5% of the national highway system is currently instrumented. Remote sensing offers a low-cost potential for monitoring the remainder of the system.)

### Weaknesses

The major weaknesses of remote sensing identified are

- Remote sensing information may not be available at critical times because of visibility problems, weather, and other factors.
- Converting remote sensing data into transportation information is usually a labor-intensive process.
- There is a lack of awareness in transportation agencies of the potential of remote sensing information. The education and marketing of remote sensing information need to be structured. Some ideas include awareness education for the federal, state, and local levels followed by application-specific education for potential users through existing professional education programs.
- Participation in the conference was lacking from some key players, such as the consulting profession, MPOs, and management-level personnel.

The technology of remote sensing is not the restraining factor in its implementation in transportation. Many technological applications are available. However, without a structured program to develop awareness of the benefits of these applications, these players will not have the information on successful applications, their benefits, and the costs of implementation that are required for serious consideration of remote sensing.

### Opportunities

The major opportunities for the use of remote sensing information in transportation are in the areas of

- Environmental assessment and streamlining;
- Operations, including ITS;
- Security;
- Identification of roadway characteristics;
- Hazard assessment;
- Performance measurement;
- Engineering of features into projects to enhance remote sensing use;
- Improvement of transportation decision processes through inclusion of information and factors that could not be collected by traditional methods;
- Collection of real-time information through UAVs; and

### Threats

The major threats identified are

- The new reality for security purposes after September 11, 2001, in the balance between public information and privacy;
- Transportation agencies' characteristic of being conservative adapters of new technology;
- Lack of readiness of most current applications for widespread implementation;
- Limits on innovative contracting;
- Danger of overselling remote sensing before commercial applications are proven; and
- Lack of trained personnel for use of remote sensing; and
- Lack of transportation agency awareness of benefits of remote sensing.

## Potential Next Steps

During the 2001 conference discussions, participants identified areas for follow-up or where the next steps should be taken to facilitate the implementation of remote sensing technologies in transportation:

1. With the USDOT–NASA Joint Program on Remote Sensing and Spatial Information, the remote sensing technology industry should consider forming additional strategic partnerships with and outreach to other efforts, including

    - National Steering Committee on Operations,
    - American Association of State Highway Officials (AASHTO) lead state program,
    - AASHTO and National Aeronautical Charting Office security efforts,
    - Federal Highway Administration core business units,
    - AASHTO GIS for the Transportation Annual Conference,
    - AASHTO spatial,
    - TRB Data Information Technology and Remote Sensing committees, and
    - USDOT efforts for the reauthorization of the TEA21 process to ensure funding is available for remote sensing demonstration deployment.

2. There is a need to think strategically about the development of remote sensing in transportation. The ITS

model of national protocols, architecture, standards, demonstration projects, and strategic deployment should be considered as the model to follow. Major issues are who should develop the strategic plan and who has responsibility for implementing such a plan.

3. Care is needed to not oversell remote sensing and turn people away from the technology. Solid information is required on those applications that really work and those that do not.

4. There must be assurance that remote sensing data integrates with other types of data and information in a transportation agency's decision support systems.

5. Incentives should be built in for transportation agencies to use remote sensing, such as funding for demonstration applications in the reauthorization of TEA21.

6. The use of remote sensing should be expanded to other modes and to multimodal and intermodal issues.

7. For remote sensing technologies that have been proven through the NCRST program, the consortia should make connections with users, select projects to go into operational testing, and develop standardized operating manuals for their application to a transportation business process. These applications of remote sensing should be implemented in collaboration with the user.

8. Workshops can be held regionally on awareness and on applications as they become available.

9. The third conference on remote sensing should continue to demonstrate the results of the research program, concentrating on applications that improve transportation agencies' business processes. After the 2001 conference, emphasis should be placed on mainstreaming remote sensing into the agencies' business processes. Strategic thinking should be initiated for marketing at the AASHTO and TRB conferences and for activities in 2003 and 2004.

## Bibliography

Jensen, J. R. The Changing Face of Remote Sensing. In *TRB Circular 360: Remote Sensing for Transportation,* TRB, National Research Council, Washington, 2001, pp. 53–64.

# Structure of the 2001 Conference and Proceedings

The 2001 Conference on Remote Sensing in Transportation—Products and Results: Foundations for the Future was structured to give attendees opportunities to exchange information on remote sensing and spatial technologies. These opportunities are presented below.

## Roundtable for States and Metropolitan Planning Organizations

The conference organized an informal roundtable for states and metropolitan planning organizations to share experiences and strategies for advancing the state of the practice. Fifteen states sent representatives to the roundtable, of which 14 made presentations. The state presentations and a summary of the discussion and the issues that were identified are in Appendix A.

## Technology Buffet

The Technology Buffet assembled poster and computer displays to showcase

- Projects and application guidebooks of the four university consortia participating in the National Consortium on Remote Sensing in Transportation (NCRST);
- Technology application projects funded by the U.S. Department of Transportation; and
- Applications of remote sensing in transportation.

The Technology Buffet was open several times during the conference, and attendees were able to view the exhibits and exchange information with the research managers. A listing of the technology buffet exhibits and contact information are in Appendix C.

## Workshops

Attendees were free to attend any of five concurrent workshops held during the first afternoon of the conference. The titles of the five workshops were

1. Introduction to Remote Sensing;
2. Successful Public and Private Partnerships for Procuring and Utilizing Remote Sensing Imagery: The Case Study of Pima County;
3. The National Map: A Framework for Institutional Interoperability;
4. Applying Remote Sensing Technology to Airports; and
5. A Fast-Track Approach to National Environmental Policy Act Streamlining and Environmental Assessment: Technology Demonstration Project.

The workshops are listed with contact information for the instructors in Appendix B.

## Main Conference

The main conference consisted of seven plenary sessions. The reports of these sessions follow.

The first session included opening comments from the conference chair and sponsors and the keynote address by Michael R. Thomas on the Top 10 Issues in Remote Sensing Technology (with Predictions): Remote Sensing and Challenges.

The next four sessions featured presentations from the four NCRST university research consortia on their current research on remote sensing products and results. Following each presentation, the session moderator delivered comments on the contents presented and moderated a question-and-answer session between the researchers and conference participants. Each university consortium was asked to prepare a short presentation for inclusion in these Proceedings, with links to their research activities for ready access to additional information. These reports and the moderators' summaries follow the proceedings of the Opening Session.

The sixth session featured a remote sensing industry forecast prepared by the American Society for Photogrammetry and Remote Sensing (ASPRS). The report on this session includes a paper prepared for the conference that summarizes the results of the ASPRS survey.

In the final session, the State of Remote Sensing in Transportation, participants heard eight presentations from experienced transportation professionals and remote sensing experts. Each participant was asked to comment on the strengths, weaknesses, opportunities, and threats for the increased use of remote sensing in transportation applications. These presentations and a summary are the last section of these Proceedings.

SESSION 1

# Opening Session of Remote Sensing for Transportation

## Products and Results: Foundations for the Future

David S. Ekern, *Minnesota Department of Transportation, Conference Committee Chair*
Robert E. Skinner, Jr., *Transportation Research Board*
Ellen G. Engleman, *Research and Special Programs Administration, U.S. Department of Transportation*
K. T. Thirumalai, *Research and Special Programs Administration, U.S. Department of Transportation*
Michael R. Thomas, *National Aeronautics and Space Administration Earth Science Applications Directorate, Stennis Space Center*

### SETTING THE STAGE: *DAVID S. EKERN*

David Ekern welcomed the participants to the second Conference on Remote Sensing and Spatial Technologies. Ekern serves as chairman of the committee responsible for developing the three conferences on remote sensing. He thanked the other committee members for their support and input and recognized the efforts of the staff of the Transportation Research Board (TRB), in particular Thomas Palmerlee and Fred Scharf, for making the conference a success. He also thanked the conference sponsors—the Research and Special Programs Administration (RSPA) of the U.S. Department of Transportation (USDOT) and the National Aeronautics and Space Administration (NASA)—and cosponsor, the American Association of State Highway and Transportation Officials.

Chairman Ekern reviewed the conference schedule and reiterated the conference's goals and objectives. He cited the Proceedings from the first conference in 2000 and the themes that emerged from that conference, namely:

- Closing the knowledge gap between the remote sensing and transportation communities;
- Enhancing ongoing communication among all groups interested in remote sensing transportation applications;
- Expanding workforce development and training;
- Enhancing technology transfer with the need to move research findings and products quickly into practice;
- Developing standards;
- Encouraging innovative partnerships;
- Defining specific research needs; and
- Promoting innovative thinking.

He asked the participants to think about four questions relative to the use of remote sensing in transportation, as they listened to the presentations and discussions:

1. What are the strengths?
2. What are the weaknesses?
3. What are the opportunities?
4. What are the threats or showstoppers?

"This year's goals are to facilitate an interaction between our professionals and those in transportation remote sensing; to enhance the understanding of remote sensing; to provide feedback on current research projects; and to bring focus to the key issues in remote sensing deployment," said Ekern. "We have tried to structure the activities over the next day and one-half to achieve these goals."

## WELCOME: *ROBERT E. SKINNER, JR.*

Robert Skinner also welcomed the participants to the conference and thanked the sponsors and co-sponsors. "The Transportation Research Board has been engaged now for 80 years to assist the linkage between the users of technology and the researchers and developers of those technologies. Probably there is no set of technologies today that holds more promise long-term for changing the daily practice in the various transportation fields than remote sensing technologies," Skinner said.

He reminded the participants of the upcoming Annual Meeting of the Transportation Research Board in January 2002 in Washington, D.C., and said several sessions would deal with remote sensing and spatial technologies: "In addition, there will be 30-some sessions addressing security activities, including a Department of Transportation megasession on the first Monday morning in which a number of senior U.S. Department Transportation officials will provide information about what is going on at the department."

## BUILDING THE FOUNDATION FOR 21ST-CENTURY TRANSPORTATION: *ELLEN G. ENGLEMAN*

Administrator Ellen Engleman began by describing the functions of the USDOT RSPA:

- "We are responsible for 2.1 million miles of oil and natural gas pipelines in the United States, the nation's energy infrastructure.
- "We are responsible for 800,000 shipments of hazardous material every day.
- "We have the Office of Emergency Transportation, which is responsible to ensure that transportation remains open in time of natural or civil disaster.
- "We have the Volpe National Transportation Systems Center in Cambridge, Massachusetts, which does excellent program management on our research and development (R&D) projects, procurement expertise, and a variety of technology core competencies.
- "We have the Transportation Safety Institute in Oklahoma City, which is focused on education and training of safety and security personnel—everyone from hazardous material inspectors to pipeline inspectors to Federal Aviation Administration accident investigators and aviation safety professions, etc.
- "We are also responsible for the intermodal thrust for research, innovation, and education at USDOT.
- "The Crisis Management Center is another function of RSPA." This is a 24/7 operational center for all the communication and coordination related to the events of September 11, 2001, that Administrator Engleman and her staff were active in handling.

Administrator Engleman highlighted the importance of transportation to the U.S. economy and the role of technology improvements. "We have a greater opportunity when you look at transportation, not as an individual vehicle, but as a system of our economy; an important application of what makes America run.

"Transportation is electronic ideas and information. Transportation is commercial activity. Transportation is the movement of goods, services, and people. Your role in remote sensing is integral in making this happen in the best way possible."

Administrator Engleman finished her remarks by offering this challenge to the participants:

"In my prior life, I was CEO of an organization. I consider myself the CEO of RSPA. For me, CEO means Communicate, Educate, and Outreach. I need your help to share those responsibilities to support this program. We cannot do this alone. The federal government is not a checkbook. The federal government is not a private pot of money. The federal government is you and me and our taxes paid April 15. So, we need to work together to invest our money and not spend our money.

"Deployment of new technologies is an evolution from research, development, demonstration, deployment, to commercialization. I know where the gap is. I know how difficult it is get from demonstration and deployment to commercialization. That is the challenge that we all face. You're looking at developing many near-term solutions as well as the long-term planning. It is critical that we help communicate, educate, and reach out to the American public, members of Congress, and other agencies about the criticality of investment in technology. I don't want 2.1 million miles of pipeline just sitting there vulnerable to terrorist attack. I want sensors to tell me how my pipelines are doing. I want self-healing pipes. I want unmanned air vehicles. I want to see technology help us. We have to track the movement of hazardous materials—we have to find it; we have to know how to move it. These are things that you can help with.

"So, think beyond your immediate application and tell me how everything you can do can give me five times the bang for the buck on the federal investment, and I will march up the mountain with you to help you find the money. But, it has to be 'a joint watch,' using some Navy terms. Why allow technology and the importance of research to get lost in the communication of everything else? Not on my watch will I allow our investment to falter or dwindle, and not on our watch will we let the American people down."

## U.S. Department of Transportation Program Progress—Building a Remote Sensing Foundation for Transportation: *K. T. Thirumalai*

K. T. Thirumalai reported that there has been significant progress since the 2000 conference in the program and work of the four university consortia in the National Consortium on Remote Sensing in Transportation.

"We set objectives to have smarter and more efficient transportation services for the 21st century in the program," he said. "Then, with partnership support, we tried to segment the technology-based development through university consortia participation. As you may appreciate, for every dollar we invest, the universities invest another dollar on that particular activity. By building the partnerships and the university consortia, we were able to cover the technology base for products. Then we coupled integrated product demonstration in partnership with service providers, and we integrated the whole activity to move as one unit in each one of the important areas that Administrator Engleman pointed out."

Thirumalai presented some highlights of projects the consortia will present at the conference, including

- Assessing the highway right-of-way for moving the CSX railroad in Mississippi;
- Blending a multisensor data collection to improve wetland identification and conduct wetland permitting;
- Applying remote sensing for improving bridge management across the country;
- Using remote sensing for intermodal applications in the Alameda Corridor in California;
- Applying remote sensing in traffic flow to bridge remote sensing and intelligent transportation system (ITS) technology in ways that enable remote sensing tools to supplement ITS;
- Managing the freight flow in urban areas and in intercity transportation;
- Applying remote sensing to open up new horizons for disaster detection and management by developing the ability to identify potential landslide areas;
- Applying unmanned aerial technology to monitor transit operations and to continuously collect data and information in ways that could interact with ITS devices; and
- Exploring sensor options, with NASA support, to provide near real-time data anywhere.

Thirumalai presented a technical and business vision for the program: "Our technical vision will be to try to apply some of the remote sensing technologies to transportation security, trying to develop those capabilities for anytime, anywhere data collection for transportation, and trying to develop those capabilities for near real-time image analysis and data information systems. Most of all, we want to develop this activity to the standards of global excellence. I do not know of any other activity in the world focusing on remote sensing in transportation. We are the first such operation. We hope to make the best use of this opportunity.

"On the business vision, we would like a nationwide application of remote sensing products and technologies for providing remote sensing to the transportation services. We would like awareness of remote sensing in each state so that you would be able to recognize the values of remote sensing tools and apply them in your activities. Above all, we would like to reach the global marketplace for some of the excellent products that are coming out of the program."

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## Top 10 Issues in Remote Sensing for Transportation (with Predictions): Remote Sensing and Challenges

*Michael R. Thomas*

I am delighted to be here. NASA is very glad to be a part of this joint program. NASA is an R&D organization. My responsibility in the applications division is to get science and technology results out of the science community and NASA and into the hands of people that can use them to really affect their operational lives and decisions. As an R&D organization, we cannot do that without operational partners like USDOT. So, we are glad to be here. We are behind the partnership 100%, and we are delighted with the early results of the program.

What really are the challenges for applying remote sensing data to issues in transportation? I think they are pretty much these:

1. Availability of data,
2. Cost,
3. Licensing,
4. Image-processing software,
5. User conservatism,
6. Training,
7. Database management,
8. Real-time imagery,
9. Currency, and
10. Communication.

The following are my views from my position in NASA on what is happening in each of these areas.

## Availability of Data

Data from satellites, airplanes, and helicopters are all limited in their own way. I think what is on the horizon is the extended use of uninhabited aerial vehicles (UAVs). The UAVs today have many advantages over satellites, primarily because you can replace the sensor payloads in them instantly. You don't have to fight the current technology lag, in which you design an instrument and by the time you go through the entire launch process, your instrument is probably 5 to 6 years old, and you can't bring it back and swap out parts. When you get a better focal plane, you don't just rush up there and change it out. With UAVs you can do that.

Some of the projects you will see here at this conference involve UAVs. While these are mostly the small ones, people are making very large UAVs with long loiter times. There is a UAV program that used to be called Tier 2 Minus, with a very large UAV that can carry hundreds of pounds in both communications and sensor payloads. The UAV flies at 65,000 ft and can loiter for very long periods of time—months, for example. When you have an on-station UAV of a very high altitude, it can be carrying communications, telecommunications packages, and sensor packages much more effectively than other alternatives. So, I think UAVs in the next 10 years are going to start to be a factor in the remote sensing business.

## Cost

Cost is constantly an issue. Remote sensing data are perceived as expensive, but I think the time is coming when we are going to start looking more at the life-cycle cost model for remote sensing data. We will find out it is not expensive. There are some significant savings from remote sensing data. We need to start looking at it as an infrastructure issue rather than as a special cost.

The selective updating of information is not routine. It is very hard to tell what you need a new picture of, because what you want is the information. You don't want the picture; you only need a picture if something has changed. We are not doing a very good job now of figuring out where we need new coverage and when we need to refresh our aerial coverage or our remote sensing coverage. I think we will start to do a much better job with that. It will be driven by just-in-time requirements such as, What is the perishability of the data? When do I have to go collect it to extract the information that I really need for this task? What is the area of coverage that I really need just to do this project? Considering these requirements will bring the cost down.

## Licensing

Licensing is going to be a continual issue until the business community, the private sector, develops a business model that gives the public sector what it really requires, which is public domain licenses. When people in the public domain buy data, the data have to be releasable. The tension is that the commercial providers want to resell the stuff. Obviously, it is to their benefit to sell it as many times as possible. I think this is just a built-in tension in this relationship. Probably business models are going to emerge and some have already, in which the baseline standard products are sold and are releasable, and they are in the public domain. On top of those, or in addition to those, value-added resellers are customizing special information packages and products that they can retain the rights to. I think we will probably see more and more of that.

## Image-Processing Software

We have a long way to go on this issue. Thank goodness we have a couple of projects that we are sponsoring in this program that I believe will help. Image-processing software right now has acquisition requirements. Different kinds of software like different kinds of data and different kinds of sources and formats. Information extraction is mostly manual these days, is very arcane, requires special training, and is not very well developed to any particular end user, a transportation user, for example. The transportation user is going to use the same version of ERDAS software with a little bit of tailoring. Also, the downstream systems, the data that you extract from the imagery, are not easy to integrate with the other systems in your business—the computer-aided design and computer-aided manufacturing systems, road centerlines, and things like that. But, I think improvements come along relatively quickly. This is one of those push-and-pull issues. If there is a demonstrated market and customer pull, then believe me, the software manufacturers will make software that addresses that pull. As the industry matures and as the use of remote sensing in transportation flourishes and expands, I think these issues will be addressed by the industry to meet the demonstrated demand.

## User Conservatism

Departments of transportation (DOTs) are not early adopters. They are risk-averse, they have limited resources, and they can't afford to be wrong, especially in days of declining budgets. It is career limiting for somebody to take a flyer on a big expensive program and have the thing flop. I don't expect operational users in a DOT or other operating agencies to be risk takers. That is not what they get paid for. They get paid for the right solution and the right cost. So, we have to recognize this reality.

This joint RSPA–NASA program is the perfect vehicle to wring the bugs out of these systems and to show people in an operational environment that higher-technology solutions to their problems exist. Those solutions are pretty robust. They are almost ready for prime time, although I would say we are right on the verge of being ready. As we develop successful operations and communicate the results to our peers, I think we will solve this problem of conservatism.

## Training

Training has already been mentioned a couple of times today. It was mentioned at the earlier conference as one of the key issues. Most of the training now is supplied by software vendors, and it is training to use their particular software. It is appropriate for their products and not based on the business model of the user. Now, we are starting to see that change a little bit through industry and professional organizations such as the American Society for Photogrammetry and Remote Sensing (ASPRS). ASPRS and other similar user organizations are prime movers in figuring out what kind of workforce development is needed, what kind of training is needed, and how to apply the training. I would like to propose that the government itself could help here by extending the use of government training centers. I think it is probably time that we start looking to create a curriculum in those government training centers for federal, state, and local users of this new remote sensing technology.

## Database Management

Today, we manage the images, which is not what we want to do. What we really want to do is to manage information. Managing the imagery is just something we do on the way to getting to the information. We do not need big, complicated image storage, retrieval, search, and manipulation systems. Typically those systems are centralized, very expensive, and slow. I don't think we want to be pushing the images around anyway. What we really want is for the information to be extracted from the image and then for that extracted information to be what we are sharing so that it is virtually available to people who need it. We need to change from a kind of image management architecture mindset to an information management mindset, in which metadata and derived information are what are widely distributed and shared.

I believe we need a system in which the updating and maintenance of information are performed at the lowest level and rolled up to synoptic data with the creation of ad hoc data products on the fly—a business model that reimburses custodians by access. The way we are attacking the problem now—the U.S. Geological Survey's (USGS) national map is an example—is with kind of a top-down information flow. The idea is that some high-level repository will send data out to the people in the field. I think that is backwards. What you see, especially in the Department of Defense (DoD), is that the people who have to maintain the data themselves, the people for whom these data are the critical issue, are the best people to maintain it. These are typically the people at the bottom of the structure—not the top of the structure. These are the people that actually collect the data. They are the ones with the most current data. It is the municipalities, the regional guys, and the state guys that really have the freshest data, because it is in their interest to collect it, to make sure it is correct, and to keep it fresh. They have to be serving this data upwards—not the other way around. So, what you need is a system that is creating larger, higher-level views, synoptic views from the detailed information that the people at the lowest levels in the organization are providing. What is the incentive for people to do that? Well, now, none. What you really need is a business model, or a financial model, that creates incentives for those people at the bottom to share their data. You need a cost-reimbursement model by access, so if the data are rolled up to a higher level, the person that collected it and created it and maintains it gets reimbursed for that, so that person can start offsetting the cost of doing the data collection and maintenance.

This is something we ought to think about. I don't even know who should think about it. What we need is a remote sensing information data czar or something like that. I have been having discussions with USGS about these kinds of things, and maybe the national map is a program that might take a look at how to organize information like this. It is probably beyond any agency like DOT or USGS or public utilities and people like that who want to share spatial information. You probably need a larger organization to be an overview organization.

## Real-Time Imagery

I know it is desirable, but there are enormous problems with real-time imagery. The first is processing. I remember 5 to 6 years ago, I was attending a briefing, and General [James R.] Clapper stood up and said to a roomful of aerospace companies, "It is not the camera, stupid." We were collecting something like 16,000 to 17,000 images a day during Desert Storm, plus aircraft gun camera video. We had 16 image analysts. We got about 25% of the data looked at on Day 1. On Day 2, we now had about 1% of all the data looked at. Day 3? Every day you get more than 16,000 new images. The fact is that you can collect a lot more images than you can extract information from. The only thing to do about it right now, I believe, is to go back to basics and ask, "What do we want this real-time data for?" and "How else could we collect it other than by remote sensing?" Remote sensing is probably not the best way, given our inability to process remote sensing data right now. Probably what we will do is fuse information collected from a number of different sources—intelligent highway systems, intelligent vehicles, and some remote sensing data maybe as required for snapshot views or for durational views. There is likely to be some mix of data that is appropriate to solving those problems.

There is also a privacy issue with real-time remote sensing imagery, which we haven't talked about very much. It is all well and good for traffic flow people to say we want to understand origins and destinations, but how many people here want somebody to know that we left this location and went to that location every time we start and use our cars? That question is bordering on a privacy issue, I think.

## Currency

Obviously, spatial information is very perishable. The timeliness of the data is related to the question you are asking. Some data don't have to be refreshed very often. Some data have to be refreshed much more often. Frequently, it is the change that you are interested in. You do not want to have to go and recollect all the data just to find out that you only had these two little changes, which you could have spot-collected if you had known.

Improved software will help us a great deal here—analysis software such as automated information extraction software and change detection software. We have invested an enormous amount of money over the last 15 to 20 years in automatic feature extraction without very much progress. I left DoD in the early 1990s and then became reacquainted with automatic feature extraction a couple of years ago. I didn't see any difference at all. It is remarkable that in almost an 8- to 9-year span of continued investment in this field, there was very little progress. I think the reason is that we are still stuck with two-dimensional data, for the most part. Frankly, two-dimensional data are just not enough to distinguish features from each other. You have to have three-dimensional data. You have to have elevation data. What you need to do a good job is the elevation, the material of the thing you're looking at, and the surface texture. If you can put those three kinds of information together, you have a signature that says it is asphalt; you've got a surface texture; and you've got an elevation. Then it is much easier to say this is a roof and not a parking lot. As those data sources become fused, operationally we will do much better with automatic information extraction, automatic feature detection, and automatic change detection. That is what we need for this industry to take off. You just can't have enough eyes on the imagery to do this manually for a large scale. But I think it is almost there.

## Communication

It is important for the people in this field to reinforce each other, and we do that a lot at conferences like this. We encourage each other to keep working. It is hard work, and so we need this support group, but we have to go beyond this. We have to get to the larger world with real results, before we can change things. I suggest we do executive seminars, which would probably be a great thing. We all know how important this field is and how exciting it is and how much it can potentially do. The important thing is that our boss knows that. We should probably think about executive-level seminars where we can bring in higher-level people and indoctrinate them or infect them with this idea.

Integrating new knowledge acquisition with professional development plans would be a great way to do this. In NASA, every employee has an individual development plan. For the people who work for me, I'll just make it part of their plan for them to acquire knowledge and skill in this area. It is relatively easy to do. You can update the skill set of your employees this way. But, unless you make it part of their formal plan, people left on their own will just tend to do what they do—a body at rest tends to stay at rest. You have to provide some stimulation. We all owe it to our employees to help them update their skill set.

Finally, intern and extern programs are terrific. We have talked about this before, having people from DOTs come to the Stennis Space Center for 3 to 5 months. We would love to do that. We would love to send people from our labs to DOT locations, for example, to stimulate the interaction and the exchange of information, so people can work with it, get their hands on it, see how it works. I think that would help us a lot.

## Conclusion

In conclusion, I think this program is very important. I think it is in the right place at the right time. It is addressing directly many of the issues that I brought up with projects that you will see briefed. It is creating synergy with other NASA and DOT programs. NASA has a state and local Broad Agency Announcement out on the street now. We would love to see those contracts be focused on transportation issues and be synergistic with the programs here in RSPA. Also, it focuses attention on modernizing, on how we view our transportation infrastructure, and on the importance of innovation. Finally, from my own parochial point of view, this program highlights how NASA can help operational agencies increase the level of technical sophistication.

## Session 2

# Environmental Streamlining

## Overview of Remote Sensing Products and Results

Roger L. King, *Mississippi State University*
Charles Gaston O'Hara, *Mississippi State University*
Ian MacGillivray, *Iowa Department of Transportation, Moderator*

### Environmental Assessments: Consortium Paper Presentation

*Roger L. King and Charles Gaston O'Hara*

The National Consortium on Remote Sensing in Transportation–Environmental Assessments (NCRST-E) is one of four consortia established by the National Aeronautics and Space Administration (NASA) and the U.S. Department of Transportation (USDOT) to lead in the application of remote sensing and geospatial technologies in the transportation industry. The primary mission of the consortium for environmental assessments is to develop and promote the use of remote sensing and geospatial technologies and requisite analysis products by transportation decision makers and environmental assessment specialists for measuring, monitoring, and assessing environmental conditions in relation to transportation infrastructure. The consortium is composed of partners from universities (Mississippi State University, Auburn University, University of Alabama in Huntsville, and University of Mississippi), government (NASA Marshall Space Flight Center and Global Hydrology and Climate Center), and businesses (DigitalGlobe, EarthData Technologies, Intermap Technologies, and ITRES Corporation). The consortium also has been asked to provide technical oversight to separately funded technical application projects (TAPs). TAPs presently under this oversight include projects led by EarthData, ICF Consulting, Veridian, the Virginia Department of Transportation (VDOT), and the Washington State Department of Transportation (WSDOT).

#### Background

Urban growth and sprawl have been attributed to a number of cultural and economic conditions, one of which is highway development. It is a conundrum as to whether highway development initiates urban growth or whether urbanization and the concomitant expansion of suburban bedroom communities into rural areas precipitate transportation development. Regardless, the growth of transportation networks associated with urban growth and sprawl translates into a host of environmental impacts, ranging from deforestation to impacts on local and regional hydrology, and accentuation or enhancement of such land–atmosphere factors as the urban heat island phenomenon. Remote sensing allows the synoptic observation and analyses of urban growth. This has been at a relatively coarse level (e.g., >30 m) via satellite platforms. With the advent of current, or soon-to-be launched, satellite-based imaging instruments that provide spatial resolutions of 4 m, it is now possible to obtain a much clearer picture of these environmental impacts. Moreover, anticipated hyperspectral sensors will provide increased radiometric resolutions that have the potential to bring about greater understanding of changes in land use and land cover. Opportunities exist for exploiting remote sensing imagery with increased spatial, radiometric, and temporal resolutions for analysis of transportation impacts on the environment. However, analytical techniques need to be developed and verified to demonstrate the viability of this kind of observational and quantitative information.

Since the passage of the National Environmental Policy Review Act of 1969 (NEPA), the Clean Air Act, the Clean Water Act, the Intermodal Surface Transportation Efficiency Act, and other related legislation, transportation agencies have been obligated to put transportation projects through an often rigorous and time-consuming environmental review process. A need to expedite the approval process was voiced in the *Transportation in the New Millennium* paper by the Transportation Research Board (TRB) Committee on Environmental Analysis in Transportation (Committee A1F02) entitled, "Environmental Analysis for Transportation Projects." However, when the author of the paper listed several technologies that have had a "profound effect in the area of environmental analysis," remote sensing was missing from that list. NCRST-E has a goal to help increase awareness and interest in utilizing remote sensing to expedite and standardize the environmental review process among transportation agencies, to make the process part of the early stages of project development and design, and to do so in a more cost-effective manner. However, to accomplish this goal, the utility of remote sensing imagery needs to be examined to determine if it in fact provides information that is a significant improvement over that from sources already available to planners, decision makers, and other members of the transportation community.

## Mission and Goals

The primary mission of the consortium for environmental assessments is to develop and promote the use of remote sensing and geospatial technologies and requisite analysis products by transportation decision makers and environmental assessment specialists for measuring, monitoring, and assessing environmental conditions in relation to transportation infrastructure. To accomplish this mission NCRST-E has four goals:

- Developing innovative remote sensing technology solutions for assessing the implications of transportation on the natural environment and protecting and enhancing the environment;
- Assessing and planning, in particular, the capabilities of new high-resolution, multispectral sensors and developing the tools necessary to efficiently extract information content from remote observations;
- Streamlining and standardizing data processing for information necessary to meet federal and state environmental regulations and requirements; and
- Increasing the awareness and understanding of remote sensing technologies and products through workshops and educational materials.

NCRST-E is exploring applications of remote sensing imagery of increased spatial, radiometric, and temporal resolution for the analysis of transportation impacts on the environment, both human and man-made. Strategic research areas of the NCRST-E encompass needs assessment for remote sensing information in transportation environmental assessment; land cover classification and change detection; wetlands mapping and assessment; air quality measurement, analysis, and modeling; watershed assessment and characterization; habitat assessment; cultural feature identification; and digital geospatial libraries for environmental assessment and planning in transportation.

## Needs Assessment

An initial task of NCRST-E was to work with TRB of the National Academy of Sciences–National Research Council in determining areas in which remote sensing could be used by the transportation industry. NCRST-E's research, technology application, and education programs respond to the needs of transportation stakeholders for evaluated environmental assessment geospatial information. These information needs were compiled through workshops, surveys of transportation agencies, and literature reviews. The NCRST-E needs assessment process and results, as well as publications for other described areas of research, can be found at the NCRST-E website: www.ncrste.msstate.edu/publications.

The following list summarizes the environmental subject areas identified by the user groups:

- Regulatory streamlining,
- Watershed assessment,
- Wetlands,
- Water quality and storm water,
- Land use change,
- Air quality,
- Species,
- Floodplain management,
- Environmental justice, and
- Cultural resources.

Several environmental process issues were also identified by the group:

- Regulatory acceptance of remote sensing data,
- Accuracy,
- Real-time data,
- Data directory,
- Metrics and measurement,
- Benefit–cost information, and
- Education and outreach.

## Field Studies

NCRST-E has a suite of ongoing field studies to ascertain and demonstrate the viability of remote sensing in environmental assessments, integration, and streamlining. Several of these projects being conducted by the university partners are detailed below.

### *Land Cover Classification and Change Detection*

For the Mississippi Gulf Coast I-10 and coastal corridor and for an area in the Appalachian region, the NCRST-E's efforts in land cover classification and change detection are producing significant results. Within the Appalachian region, 55 counties of northeastern Alabama, northwestern Georgia, and south–central Tennessee are included in a regional environmental assessment. The Mississippi Gulf Coast I-10 and coastal corridor project is investigating the changes that have occurred in the Mississippi coastal corridor over the past 30 years in land cover, land use, and transportation infrastructure. From these efforts, the consortium expects to gain valuable insight into the relationship between transportation development and long-term environmental changes and possibly even into rates of change. At the NCRST-E website, Technology Notes describing these projects are available. Also accessible is a Technology Guideline for product implementation, which provides methods and best practices for using satellite imagery to determine land cover for environmental assessment in transportation projects.

The Appalachian study area includes 55 counties of the southern Appalachian region of northeastern Alabama, northwestern Georgia, and south–central Tennessee. This region includes the metropolitan areas of Atlanta, Georgia; Birmingham, Alabama; Chattanooga, Tennessee; and Huntsville, Alabama. The objective of this study is to determine the effect of transportation development over the past 25 years on the regional environment, including changes in land cover and land use, runoff, stream flow, and socioeconomic variables. From this study, the consortium expects to gain valuable insight into the relationship between transportation development and long-term environmental changes and possibly even into rates of change. Causal factors will not be defined.

### *Wetlands Identification and Mapping*

Technology outreach among researchers, on-the-ground practitioners, and regulators is critical to the development of acceptable approaches to identifying and mapping wetlands with remote sensing products. The initial critical questions that must be answered are, "How do these data affect the assessment work flow?" and "How do these data provide results that differ from results of traditional approaches?" Working closely with consortium partners, data providers, and transportation agencies in several states, NCRST-E is answering those questions and developing a set of best practices for utilizing remote sensing data for wetlands identification and mapping in transportation projects. Initial results from North Carolina and Iowa studies indicate that the best uses will likely involve using high-resolution image and elevation data to create information products for early screening and detection of potential wetlands for alignment alternatives assessment and for field guides for wetlands biologists who must eventually "walk the line" of selected alignments. Additional studies under way in Virginia and Alabama will help refine data-processing methods, implementation uses, best practices, and limitations. The development of sound, cost-effective, acceptable approaches to the use of remotely sensed data for wetlands identification and mapping will help improve screening and selection of alignments and minimize related wetlands Section 404 actions. A Technology Guideline for product implementation and assessment streamlining is available at the NCRST-E website. Additional studies are being conducted to assess the use of similar data for watershed assessment and characterization.

### *Air Quality Measurement, Analysis, and Modeling*

Efforts to directly determine the impact of transportation on air quality have had varied success, but the use of remote sensing technology may yield important results in this area. Differential absorption LIDAR (DIAL) has been used with success to monitor atmospheric pollutants, such as nitrogen oxides, sulfur dioxide, hydrocarbons, ozone, and mercury vapors. LIDAR is the acronym for light detection and ranging. DIAL uses laser pulses to transmit and receive electromagnetic radiation. Noninvasive remote sensing DIAL systems operate on the principle that the absorption of light by the atmosphere and air pollutants has different wavelengths. NCRST-E has used DIAL technology to measure air quality, correlating air contaminant levels with vehicle traffic, meteorological conditions, and other factors to assist in developing improved models for assessing the impact of transportation on air quality and the environment. The results of early efforts are documented on the NCRST-E website, and a Technology Guideline for product implementation is also available.

### *Habitat Assessment, Cultural Feature Identification, and Digital Geospatial Libraries*

New project efforts are under way in habitat assessment, cultural feature identification, and digital geospatial libraries. All of these projects are being conducted in partnership with transportation agencies that have on-the-ground needs for research for their projects. This partnering model for developing research efforts with a technical outreach component has been identified as an important key to the eventual successful implementation of the results of NCRST-E's research efforts. Other keys to the success of this program include

- Identifying stakeholders and their information needs;
- Understanding which information needs (i.e., products) can be met with remote sensing and geospatial technologies;
- Understanding the accuracy or variance permitted in the environmental impact statement process;
- Successful technical outreach that matches real needs with relevant research;
- Effective communication of developed remote sensing technology and methods for use and application in the environmental assessment of transportation projects; and
- Measurement and benchmarking research results.

## Technology Application Projects

The longer-term research efforts of NCRST-E are linked to TAPs conducted by service providers and transportation agencies. The TAPs demonstrate how information products derived from remote sensing and related technology can be used by transportation professionals in their engineering and decision-making work flows. TAPs have been selected through a competitive, yet cooperative, process that links transportation agency partners with known information requirements and focused demonstration projects. TAPs receive guidance from and draw upon the expertise in the NCRST consortia. TAPs are 1-year projects. First-year TAPs are described below with summaries of the project results. Second-year TAPs are under way and presented with their planned application of technical expertise, project objectives, and planned deliverables.

### *First-Year TAPs*

**ICF Consulting used high-spatial-resolution multispectral satellite data to detect and map environmental features.**

Out of its Fairfax, Virginia, office, ICF Consulting worked closely with the VDOT road project to use high-spatial-resolution multispectral satellite data to detect and map environmental features. The study compared the results of remote sensing analysis with field environmental data and assessments and guided VDOT on using remote sensing data and image-processing techniques in the environmental and review assessment processes. With image data from Landsat and the IKONOS satellite, ICF demonstrated the effective use of satellite image products to identify natural and human environmental features.

ICF presented results from its study at the workshop on A Fast-Track Approach to NEPA Streamlining and Environmental Assessment: Technology Demonstration Project (see Appendix B). The presentation focused on providing transportation professionals with information about the acquisition and use of satellite imagery to assist in the environmental assessment process for transportation projects.

**EarthData International employed advanced technology in airborne imaging, mapping, and geographic information systems (GIS) to streamline the NEPA permitting process.**

The High Point, North Carolina, office of EarthData International, in partnership with the North Carolina Department of Transportation (NCDOT), employed airborne remote sensing technologies to create high-resolution planimetric and topographic mapping products. The spatial accuracy of these products was independently verified by NCDOT photogrammetrists. NCDOT design engineers used the data to create roadway designs. Wetlands field surveys, performed to the standards of NCDOT and the U.S. Army Corps of Engineers, were used to verify the results of wetlands classification performed with digital hyperspectral imagery.

The EarthData project demonstrates that high-resolution, high-accuracy data can be acquired over large project areas and that such data are suitable for the evaluation of multiple alternative corridors in the NEPA permitting process. This effort illustrates recent advances in photogrammetry and airborne remote sensing, through use of advanced airborne mapping sensors to generate high-resolution data on terrain data, wetlands data, and orthorectified photography for corridor selection and alignment approval. The technologies employed by EarthData show how early data collection and generation of necessary information products can accelerate transportation decision-making processes, because detailed information is available more quickly for all the agencies involved and for the public.

Acceptance of technologies such as the airborne Global Positioning System, inertial measurement, LIDAR, and high-resolution hyperspectral imagery by state DOTs faces numerous challenges. Highway design engineers, DOT photogrammetrists, and wetlands biologists must be confident of the reliability and accuracy of these data in a high-volume map production environment. Full acceptance of these new data types requires that the data meet specifications and be integrated into existing work flows.

EarthData's final products include a Technology Guide for implementing the data produced by advanced airborne mapping sensors in mainstream transportation practice. The workshop on NEPA streamlining at the conference (see Appendix B) provided transportation professionals with improved understanding about the procurement, integration, and use of these remote sensing information products for transportation projects.

## *Second-Year TAPs*

**WSDOT will demonstrate the use of commercial software and remotely sensed data to generate products that streamline the environmental analysis process in the planning of transportation projects.**

WSDOT will apply commercial remote sensing technologies specifically to NEPA-related analysis in planning the Washington I-405 corridor project in the Puget Sound urban area. Current regional transportation planning efforts have identified this corridor as a high priority for congestion relief. Currently, transportation planning and the NEPA process for major projects are long and costly processes that delay the delivery of transportation improvements. This project will evaluate the utility of the new technology in the NEPA process, by comparing the cost and quality of the results obtained from traditional NEPA data collection methods with the cost and quality of results obtained from the methods this project will develop, which will include remote sensing and related technology.

Among the major products of this project will be

- A spatial database of raw image data from a variety of remote sensing sources and derived and interpreted information in GIS format, including information on land use and land cover;
- Software procedures that access multiple data sources to derive information on land use and land cover and to identify and delineate areas where proposed transportation development might cause adverse environmental impacts; and
- Cost–benefit analysis that compares—in cost, content, accuracy, and timeliness—products derived from conventional data-gathering practices with products developed in this study.

**VDOT will automate wetlands identification to meet federal reporting requirements.**

VDOT will demonstrate that remotely sensed wetlands data, when introduced early in the planning process with other available GIS data layers, serve as a good preliminary indication of potential impact and as an accurate guide to field reconnaissance and surveying. The as-is planning process follows the 1987 *Corps of Engineers Wetlands Delineation Manual* with supplemental information from the National Wetlands Inventory data, soil survey data from the U.S. Department of Agriculture National Resource Conservation Service, aerial photography, and field reconnaissance. The investigation includes plans to review VDOT wetland identification processes for projects, review completed processes for US-17, acquire ERDAS Sub-Pixel software, identify and acquire imagery, establish reflectance ranges for vegetation types, refine wetland classification routines, and output wetland polygons to compare with existing GIS data, such as soil type, and with National Wetlands Inventory data. The areas classified as wetlands will be compared with existing field reconnaissance data. The derived wetland polygon data will be made available in the VDOT GIS and integrated with other enterprise GIS data. Distribution of data will be enabled by means of Oracle, ESRI SDE, and ArcIMS software.

**Veridian will develop a regional database for transportation planning for southern and coastal areas in Mississippi.**

Transportation planning can benefit significantly from use of regional environmental databases. Among the most significant benefits is the ability to rapidly assess the impacts of changes in alignment configuration. This project focuses on the development of a regional database for southern Mississippi for the purposes of transportation planning. Beginning with a regional database developed for the Gulf Regional Planning Commission, Veridian will use remotely sensed imagery to update existing vector data layers. The database will then be shared via an Internet Map Server (IMS). Another portion of the study involves analysis and comparison of various digital elevation data sources. Existing U.S. Geological Survey information products and products derived from remote sensing analyses will be compared with ground truth data to determine if any of these data sources meets the needs of transportation planners. In addition, a transportation-planning tool will be developed to assist engineers and environmental scientists in evaluation of environmental impacts.

This GIS-based tool will allow the user to specify an alignment configuration and right-of-way requirements. With this information, the tool will query the database for specific environmental features, calculate the amount of impacts for each feature, and develop an impact matrix. Finally, the tool will allow the user to develop “strip maps” along the corridor at a specified scale. These maps can be printed and used in the field. If possible, this tool will be built upon the framework of the Veridian Battlespace Mapper tool originally designed for Department of Defense applications.

## Conclusions

NCRST-E is a multiyear research and education center funded by the USDOT to facilitate the use of remote sensing and geospatial technologies. NCRST-E has developed partnerships with DOTs in several states for the utilization of imagery in environmental subject areas and processes. It serves as a national center of excellence for the use of remote sensing and other geospatial technologies for the transportation industry.

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# Moderator Summary

*Ian MacGillivray*

When I was introduced to environmental concerns a long time ago, when we were looking at developing challenging projects, the first thing that hit me was how overwhelming the challenge was. Finally, 20, 25, 30 years later, I'm beginning to see some promise that maybe we can actually do what we were asked to do under NEPA or other legislation. There is a lot of promise. The potential is now starting to show.

I think we are a little ways away from getting it all done, but the pace of development is accelerating. The potential is being demonstrated.

Environmental streamlining: what is that all about? To folks that are not in the middle of it, what it means is faster, more than anything else. It takes a long time to develop transportation projects. In fact, in our state we have gone from a time not too many years ago when a designer could develop a project in a couple of years, to the point that now it takes 6 to 9 to 11 years to develop major projects. We have been addressing that by changing management practices, and on occasion we have even been able to get it down to a 5-year turnaround for developing a project. That is a real accomplishment, but the public thinks that is a joke.

Better, quicker, cheaper—I want to turn that phrase around. Better is useful. Cheaper is okay, because that will close the sale for sure. But quicker is the most important. That affects our credibility and our ability to do our job and to have the work accepted by decision makers, and "decision makers" means the public. We need to be more responsible to and inform the public about what we are doing. Remote sensing is a key opportunity and tool for us to do a better job of that.

As a nonpractitioner, I've seen the emergence of these tools in the last few years. I don't know a lot about the design of a sensor. I do know something about the use of the information when it comes down to the design and operation of a transportation facility. I am quite impressed. I have also now begun to recognize that we have a Catch-22 at work, and perhaps we have a new challenge to all of those folks. The Catch-22 for us at the DOT and the resource agencies is that we need to understand what you are trying to tell us and what you are demonstrating, before we can adopt it. But, we will not apply it on projects unless we understand it, and we are not going to learn unless we apply it.

One final observation from my view: I appreciate that the university consortia, with support from RSPA, are here leading and bringing to us the development and application of remote sensing technologies. We do need to understand. We do need to get into it. We are not going to get into it with our old traditional approach. The role of universities is to develop that education and understanding, and that is what this conference and program are all about. So, what I need to say to my counterparts at the DOTs is that you need to get involved with your universities and become participants and learn in that fashion. That is what we're doing in Iowa, and we're seeing that return on investment now.

SESSION 3

# Transportation Planning

## Overview of Remote Sensing Products and Results

Mark R. McCord, *Ohio State University*
Mark Hickman, *University of Arizona*
Michael S. Bronzini, *George Mason University*
Prem K. Goel, *Ohio State University*
Richard B. Gomez, *George Mason University*
Carolyn J. Merry, *Ohio State University*
Pitu B. Mirchandani, *University of Arizona*
Joel L. Morrison, *Ohio State University*
Mark E. Hallenbeck, *Washington State Department of Transportation, Moderator*

### REMOTE SENSING OF TRANSPORTATION FLOWS: CONSORTIUM PAPER PRESENTATION

*Mark R. McCord, Mark Hickman, Michael S. Bronzini, Prem K. Goel, Richard B. Gomez, Carolyn J. Merry, Pitu B. Mirchandani, and Joel L. Morrison*

This paper presents transportation flow problems for which remote sensing has been successfully applied and discusses recent results pointing to other flow-related problems for which remote sensing could be beneficial. The scope is limited to that considered in the U.S. Department of Transportation's (USDOT) National Consortium for Remote Sensing in Transportation (NCRST) (see www.ncrst.org/ncrst.html). As considered in the context of these consortia, remote sensing encompasses sensing from space- and air-based platforms. Compared with loop detectors, road tubes, and increasingly operational side-of-the-road sensors, remote sensing from space and air offers the potential for wide-area coverage, synoptic views, rapid deployment, and flexible maneuverability. However, these potential advantages generally come at the price of decreased temporal resolution. Moreover, the remote sensing of transportation flows from space- and air-based platforms is a relatively undeveloped civilian activity, and many of the interesting applications may not yet even be identified.

This paper highlights numbers of space- and air-based applications and technologies, although probably not all applications have been found. Similarly, there is no attempt to list all applications that likely could eventually benefit from remote sensing. Rather, studies are presented that have already produced concrete results to indicate that a flow-related problem could benefit from remote sensing. Several ideas for additional applications warrant investigation, but no results are known in support of the applications. It is hoped that this paper will generate other ideas and the motivation to pursue them.

The paper is organized into three major sections. The first section discusses actual transportation-flow-related applications of air- or space-based remote sensing. The second presents recent results that indicate as-yet undeveloped applications for which remote sensing may have potential value. If the promise of these applications is to be fulfilled, breakthroughs will be required in automatic vehicle detection. The third section reviews recent progress in this area and discusses work in uninhabited autonomous vehicles (UAVs) related to remote sensing of transportation flows. The paper concludes with brief remarks.

## Present Applications

The National Consortium on Remote Sensing in Transportation–Flows (NCRST-F) (see www.ncrst.org/research/ncrst_f.html) is the USDOT remote sensing consortium devoted to transportation flow activity. Much NCRST-F work centers on developing the field of remotely sensing traffic flows from air or space for the purposes of monitoring, management, and intermodal planning and analysis. There are several examples of successful applications. Most major metropolitan areas provide helicopter-based traffic reports during peak periods. Similarly, during large special events, such reports are common and helpful. The sensing in these routine applications is rather low-tech: a trained reporter observes flow data. However, the synoptic views gained from the air offer distinct advantages compared with the local information collected by a set of ground-based sensors. There have been other, perhaps less well-known, applications of space- and air-based remote sensing. The following applications are highlighted because of their potential for widespread, if not routine, use.

At the request of a private trucking company, Space Imaging LLC in 2000 used panchromatic 1-m imagery obtained from sensors carried on the IKONOS satellite. Although details of the study are not publicly available, the company has given access to general information (Anderson and Young, 2001) on the company's successful use of the imagery to quantify truck traffic on I-25 near Denver, Colorado, with special emphasis on long trucks. The long trucks (>60 ft) served as an indicator of interstate truck traffic, information that is not readily available from other sources. Vehicles (including passenger cars) are clearly visible in the 1-m imagery shown. The number of trucks observed in the imagery matched ground counts of the trucks to within 10%. Although this is not mentioned in the report, the 10% discrepancy is not an indication of the accuracy of the imagery. Rather, it likely reflects fundamental differences between traffic density, which is observed in image snapshots, and traffic flow, which is used largely because of reliance on location-specific ground sensors available to traffic monitoring crews. In fact, if the ground counts had been converted to density estimates, the results would read: "The ground-based counts matched the image-based counts to within 10%." Moreover, analysis conducted by NCRST-F researchers indicated that discrepancies between average density-based flow estimates and true flow averages decrease rapidly with the number of images taken at different times. Even with a single data set in the Space Imaging application, however, the company reported client satisfaction.

Private companies also provide air-based traffic surveys for transportation planning and management. For example, the Maricopa Association of Governments used such surveys to study traffic congestion on freeways and major arterials in the metropolitan area of Phoenix, Arizona (Maricopa Association of Governments, 2000). Skycomp Inc. collected aerial photographs of peak-period traffic congestion from a fixed-wing aircraft. Photographs of different locations were taken at 20-min intervals on 4 days during peak periods in the morning (7 to 9 a.m.) and evening (4 to 6 p.m.). This yielded a collection of 48 photographs of each location (6 photographs in each of the morning and evening periods for each of 4 days).

The photographs were manually reduced to obtain vehicle queue lengths at major intersections and vehicle densities on freeway segments. Technicians manually counted the number of queued vehicles at the intersection approaches. Separate counts were made for left- and right-turn and through-movement lanes. These queue lengths were combined with the traffic and turning movement counts (obtained by another contractor) to estimate the stopped delay at the intersection, which is the typical level-of-service measure in arterial capacity analysis. On freeways, vehicle densities were determined directly from the aerial photographs for well-defined segments. Different classes of vehicles (passenger cars, trucks, tractor-trailers, and buses) were considered, and passenger-car equivalent factors were applied to determine a density measure of passenger cars per lane per mile. This density value was used with the *Highway Capacity Manual* (TRB, 2000) to determine the freeway level of service. Separate studies were conducted of the general-purpose lanes and of the high-occupancy-vehicle lanes in the study area.

Determination of locations generated by the Global Positioning System (GPS)—of emergency vehicles, snowplows, long-haul trucks, and other fleets of vehicles for purposes of managing operations and planning—is fairly standard practice and outside the scope of air- and space-based remote sensing in this paper. GPS is arguably the best way to monitor locations of these vehicles now and in the foreseeable future. Still, there is potential value in air-based imagery as a backdrop for GPS locations. 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 (see www.ncrst.org/research/ncrst-f/library.html). The product served as visual support for investigating suspected driver deviations from scheduled routes.

This 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. A GPS-based location system is used to obtain real-time passenger information and for off-line performance monitoring. Among the applications of this information, bus locations are displayed in real time at a website on a crude map background (see www.blis.units.ohio-state.edu). NCRST-F is also providing users with the option of seeing the bus locations on an image backdrop of the area. This image offers a higher-tech and more aesthetically pleasing presentation of the information. If marketed well, such an appearance could generate a more positive image and greater support among transit users and nonusers alike.

Imaging methods not directly related to remote sensing of transportation flows but developed by NCRST-F researchers in other contexts have found their way into real applications. EarthData was hired to provide near-real-time airborne data on hot spots at the World Trade Center twice daily for more than 1 month after September 11, 2001. Data collection was then reduced to once a day and eventually to once a week. Sample data can be found at www.newyork.earthdata.com. The images were acquired with a 4K-by-4K digital camera, a technology developed by NCRST-F researchers. This camera and the direct georeferencing concepts used, also pioneered by NCRST-F researchers, were necessary for providing the information in near–real time. These researchers, who have a long-standing professional relationship with EarthData, are refining these same hardware and software concepts for near-real-time flow detection.

## Promising Areas for Development

In addition to successful implementation of air- and space-based remote sensing of transportation flows, recent results point to the potential to develop other applications.

State DOTs and local agencies commit large amounts of equipment and personnel resources to estimating systems' traffic statistics. Two of the most commonly estimated statistics are average annual daily traffic (AADT) on individual highway segments and vehicle miles traveled (VMT) on a network of segments. Previous analysis (McCord et al., 1995) indicated the potential of detecting vehicles in 1-m satellite imagery and distinguishing small (passenger cars) from large (trucks) vehicles in the imagery. These results have been validated in available IKONOS satellite imagery, such as that used in the Space Imaging study presented above. This source of data could conceivably be added to data collected from ground-based sensors to produce better AADT and VMT estimates. However, high-resolution sensors are carried on satellites in low orbits that do not allow high-frequency temporal sampling of the links. Moreover, the satellite data consist of "snapshots" of the highway densities, which would then be converted to equivalent volumes corresponding to extremely short (e.g., 5-min) time intervals. These extremely short-interval counts would then be expanded to daily counts that could be combined with the ground-based data. In comparison with ground-based data only, these conversions and expansions would be subject to additional error or "noise." The question then becomes, Is the noise in converting short-interval observations to daily volumes too great and the sampling frequency too small to allow the satellite-based data to improve AADT and VMT estimates?

Computer simulation models developed by NCRST-F researchers show that the addition of even noisy satellite data obtained with low temporal frequency to collected ground-based data can lead to large reductions of errors in AADT and VMT estimates under a wide range of conditions. The results also show that using satellite-based data allows for dramatic reductions in ground-based sampling efforts and in the number of required fixed traffic recorders, while it also decreases AADT and VMT errors (McCord et al., 2002). States use a combination of permanent automatic traffic recorders (ATRs) and a coverage count sampling program. The results showed that a scenario of satellite-based data, some ATR data, and no coverage count program outperformed a scenario of more ATRs, an aggressive coverage count program, and no satellite-based data. Additional analytical results illustrated that the assumptions in the analysis involved with converting short-term satellite observations to 24-h volumes may be overly conservative (Goel and McCord, 2001). A proof-of-concept study is being conducted with actual, rather than simulated, IKONOS imagery and ground-based data to estimate AADT on selected highway segments in Ohio.

Remote sensing also could be used to track turning movements and improve the estimation of dynamic and static origin–destination (OD) flows. OD flows are among the most fundamental demand characteristics for transportation flow planning studies and real-time traffic management. Observed traffic counts on network segments—generally obtained from in situ traffic recorders—are valuable data that can lead to improved OD estimates. Indeed, commercially available software packages now include procedures for accomplishing this task for planning applications. Air-based sensing can cover more of the network than that covered by a limited number of in situ sensors. Air-based sensing also offers the potential to track individual vehicles or platoons of vehicles along portions of their OD routes.

The potential was investigated, therefore, of improving OD estimation with data collected from airborne remote sensing, which is collected more easily than data gathered from ground-based sensors. Researchers collected 3 h of video data from a tower on the Ohio State University campus with three camera views covering portions of a campus subnetwork with three intersections. The video data were digitized, and vehicles were matched across the three scenes. These processed data served as a data set of true OD flows, intersection turning movements, link volumes, and travel times. With a Kalman filtering approach (Ashok and Ben Akiva, 2000), 5-min OD flows were estimated from historical estimates of the flows and assignment matrices that relate OD flows to link flows. The estimates were produced under a set of scenarios representing different traffic surveillance assumptions, and estimates were compared with the true flows obtained from the video data. More detail on the study can be found in Mishalani et al. (2002) and Gopalakrishnan (2001). In brief, adding turning movement observations to the traditional link volume observations decreased the normalized root-mean-square-error (RMSE) of the 5-min flow estimates by more than 20% under the base case assumptions. Similarly clear performance improvements were observed across a wide range of conditions with a sensitivity analysis of the historical estimates on the magnitude of the OD flows. Moreover, when the historical estimates of the assignment matrices were poor, adding link travel time observations to the surveillance data led to a reduction in RMSE of more than 10%, compared with the RMSE when only the link and intersection turning volumes were used. In addition, when aggregating OD flows across the 3-h period, adding observed intersection turning movements to the OD estimation led to an RMSE reduction of more than 25% with base case historical estimates. However, adding observed link travel times led to no further reduction in RMSE even when a poor estimate of the assignment matrices was used, which indicates that the use of travel time data is important only when considering dynamic OD flows.

Although the network was small, it is believed that this is the first study with empirical data to illustrate the value to OD estimation of observing turning movements and link travel times—two flow variables likely better measured from remote sensing than from traditional ground-based detectors. The results showed that the importance of link travel times increases as the quality decreases of prior estimates of the assignment matrix, at least for dynamic flow estimation. The quality of assignment matrix estimates would likely be poor for large urban networks, and the empirical results implied that the positive effects of using air-based remote sensing surveillance would increase for the larger networks that are of interest to transportation planners and traffic managers. The study was extended to address the effect of partial spatial and temporal sampling of turning movements and link travel times. Larger networks with route choice options also came under consideration.

Vehicle velocities are also among the flow-related parameters of most interest to transportation planners, engineers, enforcement agencies, and policy makers. Ground-based sensors can be used to estimate vehicle velocities at locations on a highway during a time interval. So-called floating cars often track average velocities along highways. However, airborne sensors can be more easily maneuvered to sample multiple locations and have the potential to collect velocities of multiple vehicles along a highway section. These data would lead to more direct and less subjective estimates of space mean speeds and their variances, which are of more fundamental interest to traffic flow applications than time mean speeds collected at points on the highway.

Therefore, NCRST-F researchers investigated the estimation of vehicle velocities from airborne imagery. They collected video data from a helicopter platform on two separate occasions in the Tucson, Arizona, area, in summer 2000. Video data of several arterials and freeways were collected with a handheld digital video camera from altitudes of 600 to 1,500 ft. A second flight in May 2001 collected data at altitudes of 800 to 1,200 ft over a selected arterial and I-10. Sensor placement and orientation were more carefully planned in this second flight, and with a GPS unit, location and altitude of the helicopter were recorded more accurately. Also, ground cameras and a GPS-equipped floating car were used to produce ground-based velocity estimates. Details and an extended analysis of the experiment, including analysis of the sensitivity to sampling intervals and scaling issues, are in Hickman et al. (2001). Because of the small sample size, the results can only be considered indicative. Still, they show that the helicopter-based estimates of space mean speed matched the ground truth estimates better than estimates derived from traditional floating cars. (In obtaining average highway velocities, driver subjectivity in determining and matching average highway speed is always of concern with floating cars.) The airborne video data also yielded information on across-vehicle velocity variability that is unavailable from floating car data. A level-of-service analysis also highlighted the ability to detect variations in flow-based performance measures among segments. Such variations could only be obtained with a large amount of ground-based collection equipment. The study also determined a number of other flow parameters (Angel and Hickman, 2002; Angel et al., 2002). Flow data collected from helicopters or other airborne platforms may seem expensive when the collection cost is attributed to only one data set. However, because of the richness of the types of data derived from airborne platforms, the cost of collection can be spread widely, and the cost per useful data item can be driven down markedly.

## Progress in Automation

To realize the potential of these promising applications would require developments in identifying and, in the case of the velocity and turning movements, matching of large numbers of vehicles across frames. In addition, OD estimation and velocity determination would be of value in real-time applications. Therefore, it would be important to detect, classify, and match vehicles with little, if any, human intervention. NCRST-F researchers have been developing automated image-processing approaches for identifying and classifying vehicles.

Researchers attempting to detect vehicles in high-resolution (1-m) panchromatic satellite imagery, the type of imagery that would be used in the AADT and VMT estimation application described above, have been pursuing several approaches in parallel. Two of these are described below, both of which considered the comparison of the image of interest with a background image representing the highway without vehicles. On low-vehicle-density highways, this background could conceivably be constructed by averaging several images of the same highway taken at different times. Low densities would lead to low probabilities of vehicles present at the same locations in a set of images. The highway signals would, therefore, tend to dominate the vehicle signals in the average. For example, in an empirical trial with a series of digitized aerial photographs on Ohio rural Interstates, vehicle signals were almost entirely eliminated when five images in the average were used (Merry et al., 2001). The researchers had access to only a few IKONOS images with no repeated images of the same location. They, therefore, created a synthetic background image by manually replacing gray levels of pixels where vehicles were present with gray levels based on surrounding highway pavement in the image.

The first approach relied on principal component analysis (PCA), which involves rotation of the original data into uncorrelated variables that account for variability in the data. The sum of and absolute difference (absolute value of the difference) between the image of interest and the background image were first calculated. Mean and standard deviations over small spatial windows (2- × 2-pixel windows) were then computed for both the sum and absolute difference images to produce four input bands to the PCA algorithm. Four PC bands were produced as outputs, and a binary thresholding operation was performed on the third band, which showed very good performance for vehicle identification. (Researchers are investigating joint thresholding on the third and fourth bands, but no results are reported yet.)

The second approach (McCord et al., 2000) simultaneously transformed the background image to the conditions of the image of interest and considered the difference between the two images to assess whether each pixel should be considered dynamic or static—whether a pixel appears very different from the corresponding pixel in the background image and, therefore, was likely imaged when a moving object was occupying its location, or whether it appears to be representative of the static, background pavement conditions. This procedure was iterative and based on the use of natural splines and an expectation–maximization approach to estimate the distributions of the gray levels of static and dynamic pixels in the difference images. Once the procedure converged, an output probability map assigned to each pixel a probability for being static and therefore discarded as a candidate for categorization as a vehicle pixel. A binary thresholding operation was then performed on this probability image.

In both approaches, the binary threshold separated pixels into those that should be further considered as possible vehicles and those that should be eliminated from consideration. Adjoining pixels retained for further consideration as vehicles are clumped together, along with rules based on the size and geometry of the clumps, allowed classification into small or large vehicles or nonvehicle objects. Results are promising for both approaches (see www.ncrst.org/research/ncrst_f/library.html), but were based on a limited number of satellite images and scanned air photographs.

Other NCRST-F researchers are considering image processing of airborne video data. Compared with 1-m satellite data, vehicles in video data cover a large number of pixels. There are also an extremely large number of images in a time interval—on the order of 30 images per second for video versus a single or perhaps stereo pair of images every few days for satellite imagery. On the other hand, the helicopter platform is much less stable than the satellite platform, which increases the complexity of video image processing.

The currently pursued approach to automatically processing the helicopter-based video uses edge detection techniques on each frame retained for analysis (Hickman et al., 2001). The coordinates, scale, and orientation of each frame are used to transform a subsequent frame to the same reference system as the first frame. The two frames are subtracted with the expectation that only dynamic (moving) objects will remain. To date, researchers have successfully identified vehicles with this approach in less than 0.5 s. The goal is to identify and match vehicles in the 2-s interval between successive image acquisitions targeted for velocity determinations. Researchers are pursuing a maximum likelihood estimation technique to accomplish matching in the 1.5 s remaining.

Other remote sensing technologies, proven in applications outside of transportation, appear attractive to the sensing of transportation flows. Because they detect the more detailed characteristics of the sensed objects, they offer a better chance of distinguishing vehicles from the highway and of matching identical vehicles sensed at different times. Matching vehicles is important in tracking turning movements and in determining velocities, two tasks of special concern to developmental efforts.

Multi- and hyperspectral sensing is one attractive technology. Several spectral databases are available in defense and civilian agencies, but they deal mostly with signatures of natural materials or military vehicle paints and finishes. Therefore, NCRST-F researchers conducted field measurements with a portable spectroradiometer of vehicle paint and pavement signatures. Measurements were taken on 2 days in a parking lot on the University of Arizona campus: on October 16, 2000, a bright and clear day, approximately 20 cars and 5 pavement types were sampled, and on April 20, 2001, a cloudy day, approximately 20 cars of different colors were measured.

Plots of reflectance as a function of wavelength between 300 to 2500 nanometers can be found in Schowengerdt et al. (2001). Figures 1, 3, and 4 in their report show that the different vehicle colors were distinguishable from each other and from pavement backgrounds throughout the visible to shortwave infrared spectral regions. Figure 2 in their report shows that different pavements can also clearly be distinguished. Developing an operational spectral signature library would require a much more extensive sampling program than that undertaken in this preliminary study. However, this is the first study demonstrating the ability to recognize civilian vehicles with multispectral imagery.

Light detection and ranging (LIDAR) is another sensor that has been gaining popularity in the remote sensing community. LIDAR data would provide over time the $(x, y, z)$ coordinates of a very large number of points for a relatively extended area. The data can conceivably be used to detect vehicles on a highway surface (the highway has lower $z$-values than the vehicles do). The data would also be conducive to classifying individual vehicles by three-dimensional estimates of size and shape, and these characteristics can be used to match identical vehicles over time. Moreover, the stark numerical contrasts in vehicle $(x, y, z)$ signatures from the background highway are appealing for automated image processing. As an active sensor, LIDAR can also image at night and under reduced lighting and other adverse conditions.

Although LIDAR seems to be of increasing interest to the remote sensing community, there appears to be no investigation in the civilian community of its use for vehicle detection and identification. Woolpert, LLP, donated LIDAR data obtained over US-35 in Green County, Ohio, to NCRST-F researchers, who used the corresponding U.S. Geological Survey digital orthophoto quarter-quadrangle to serve as an image backdrop. Large vehicles (trucks) could be clearly identified by visual inspection of the data (see www.ncrst.org/research/ncrst-f/library.html). The LIDAR data collection effort was not designed for vehicle identification, and the researchers are investigating whether this data set will allow identification of smaller vehicles (passenger cars), or whether a denser grid of LIDAR returns is required. Vehicle velocities could also conceivably be estimated from the speed of the aircraft, the LIDAR scan rate, and an assumed vehicle length. The researchers are pursuing this innovative use of LIDAR data and testing it with their empirical data.

A major impediment to determining velocities from imagery, especially in near–real time, is the need to determine ground-control points that reference overlapping images taken at different times to the same coordinate system. NCRST-F researchers have been refining their expertise in the GPS, the inertial navigation system, and geometric calibration of sensors to estimate and improve the accuracy of automatically determining geocoordinates of image pixels on the ground without the need to resort to the intermediate step of matching ground control points. They believe that they can obtain between 2- and 20-cm accuracy on the ground, depending on altitude and calibration quality (Brzezinska et al., 2001). Even under the worst-case assumption of uncorrelated errors, the 20-cm error would correspond to extreme velocity errors of less than 1.5 and 0.75 km/hr when the times between images are 1 and 2 s, respectively. The researchers are continuing efforts to decrease georeferencing errors. Nevertheless, these already promising results have led them to join with researchers who have been estimating velocities from helicopter video on a new project that will demonstrate the ability to estimate velocities directly (i.e., without matching ground control points) with these accuracies.

In addition to sensors and processing developments, an expanded array of platforms is encouraging for the development of space- and air-based remote sensing of transportation flows. The feasibility of obtaining high-quality, high-resolution imagery from nonmilitary satellite platforms has been proven with empirical IKONOS imagery. Fixed-wing and helicopter platforms have been used operationally in traffic management and monitoring for some time. UAVs may soon offer another platform for data collection.

Bridgewater State's Moakley Center for Technological Applications developed a small UAV and equipped it with an inexpensive 35-mm camera and two video cameras (see www.ncrst.org/research/ncrst-f/library.html). This low-cost, commercially available UAV, which was controlled through a line-of-sight video link, collected imagery to assist in monitoring commuter rail park-and-ride lots and vehicle and pedestrian traffic at an intermodal facility. GeoData Systems, Inc., and DBR & Associates will soon be demonstrating the use of a larger UAV for traffic surveillance on an arterial (US-13) and freeway (I-64) near Chesapeake, Virginia (GeoData Systems, Inc., and DBR & Associates, 2001). The Airborne Data Acquisition System (ADAS) will use high-resolution video imagery to capture traffic data conditions during several 15-min periods while loitering over arterial intersections and a freeway interchange and flying along a 5-mi stretch of highway. The companies also intend to make ADAS available on a standby basis to monitor traffic conditions around a future incident in the study area. Plans are being formulated to demonstrate ADAS to state and local transportation officials in the Central Ohio area in 2002.

## Remarks

The use of air- and space-based remote sensing of transportation flows cannot be considered extensive. Nevertheless, several flow-related applications have found their way into the marketplace. Several other large-scale and recurring flow problems could likely benefit from remote sensing, and only those with promising results have been discussed in this paper. Many other as-yet untested applications may have similar potential. To realize this potential, additional research and development are required. In many cases, the cost of the remotely sensed data to the users must also be reduced. With the expected increase in supply of available satellite and airborne platforms—manned and eventually unmanned—the cost of data should decrease, and the interest in exploiting the platforms should increase. The time, therefore, seems appropriate for concentrated development of these areas.

## Acknowledgments

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## Moderator Summary

*Mark E. Hallenbeck*

I want to compliment Ohio State University and its consortium partners. If you look from a year ago to where we are today, I think they have made a lot of wonderful progress. A year ago, I thought the area of traffic flow had the farthest to go of all the consortia. Now, we still have the farthest to go. It is like measuring infinity. How big is infinity? How far is it? We have a long way to go, and yet I think even more now that flows has the biggest potential of all the groups that you'll hear about today.

We've talked about counting cars from space as long as I've been involved in counting cars, which is longer than I care to admit, but there is so much going on when it comes to understanding traffic. There is a huge body of knowledge that we have to manage in how we operate transportation facilities. It is not a new thing for state DOTs and local agencies, but its importance has changed in the last few years. In Washington State we found out a lot earlier than other parts of the country that we could not build our way out of traffic. We got the operations message and had to do operations earlier than much of the rest of the country.

One thing we found out is that you cannot operate something if you do not understand what is going on. We cannot afford, under conventional technologies, to obtain the information necessary to understand and manage operations.

I want to take exception to some earlier presentations concerning the collection of data from remote sensing—that is, data are not information. We don't need data. We need information. That is the key between going from gigabytes worth of images, sensors, and hyperspectros to information on operations.

We do need data, but operations data are new to us. Very few cities have ramp controls. We still do traffic signal operations as it was done in 1920. If we are very lucky, we have made it to the 1960s. We have technologies that can allow us to do adaptive traffic controls, that can change traffic signals on the basis of the flow that is there, or better yet, the flow that will be there 5 min from now, but only if we have sensing, and we do not have it.

Here is the opportunity for us and for remote sensing. To do operations, we have to cover enormous geographic areas for both the data and, more importantly, information. The time frame is, in fact, continuous. We do not have to be out there continuously, because we do not have to operate the whole roadway system hands-on right now, but we do need this mix of continuous, forever operations. You are going to operate the Beltway here in Washington, D.C., and we are going to operate Interstate 5 continuously because they are so busy. There are other sections of roadway that only need to be operated hands-on periodically. When was the last hurricane that hit Florida? When is the last hurricane that hit Mississippi? When were the floods? When is the tornado? We have to be able to respond operationally and ask, What roads are flooded right now? What roads are open? Where is the traffic? How can we route it from here to there? That is a huge sensing problem, but it is also a huge data manipulation problem, because we do not need to know how many pictures we have. We have to know where the car is stuck, which roads are open, if that bridge is closed because it is flooded or if that bridge is closed or open, and if vehicles can be routed over there. That is a wonderful, difficult data-handling process.

The good news is that these researchers are heading in all the right directions. We now have small airplanes—UAVs—that can be launched on 15-min notice. A UAV can be sent up there and used for real-time video surveillance in a flood situation. That is great! The next step: that plane has to fly in a hurricane. As I said, we have a ways to go, but the military is flying remote vehicles at 65,000 ft continuously over Afghanistan right now. That cost is the wrong level of cost for us traffic operations folks, but cost is relative. What is the value of the life you can save if you have to evacuate the Florida Panhandle? We are not only talking about traffic operations; we are talking about national security and emergency management, and that allows us to look to remote sensing. It has a very different scale than we, as traffic engineers, are used to. It is good for us, not only at the scale of correctly taking care of those emergency and security events but also at the scale of enabling us to get to work on time on Monday.

SESSION 4

# Infrastructure and Engineering

## Overview of Remote Sensing Products and Results

Michael F. Goodchild, *University of California, Santa Barbara*
Shauna Hallmark, *Iowa State University*
Val Noronha, *University of California, Santa Barbara*
John J. Conrad, *Washington State Department of Transportation, Moderator*

### INFRASTRUCTURE AND ENGINEERING: CONSORTIUM PAPER PRESENTATION

*Michael F. Goodchild, Shauna Hallmark, and Val Noronha*

The National Consortium on Remote Sensing of Transportation–Infrastructure (NCRST-I) addresses a number of U.S. Department of Transportation (USDOT) strategic goals—safety, mobility, economic growth, security, and organizational excellence. Over the last two decades, state DOTs have faced increasing demands for accountability in transportation infrastructure management, such as the Highway Performance Monitoring System and the Government Accounting Standards Board 34 (GASB-34). Remote sensing offers new sources of data that were not available previously. To be most useful, data from remote sensors must be integrated with computer-aided design databases, current geographic information system (GIS) data, traffic sensors and cameras, and current transportation needs and practices as well as evolving information demands such as from intelligent transportation systems (ITS). Security must also be taken into account.

Our approach to infrastructure recognizes three essential components:

- The *objective* of infrastructure management, which ranges from operational tasks of maintenance to tactical tasks of renewal and construction and strategic tasks of planning and design;
- The *assets* that are the focus of management, including pavement, bridges, pipelines, rail lines, harbors, and airports; and
- The *information* needed for management, recognizing in particular the aspects that are particularly well served by remote sensing, including information on location and on change through time.

If information technology is to be successful in practical, everyday infrastructure management, it must be integrated and comprehensive, easy to use, and capable of providing answers to management questions rapidly. All too often in the past remote sensing has delivered abundant data, but in forms that require extensive preprocessing and a high level of user skill. New technologies emerging in the areas of digital libraries, search engines, and GIS offer much more appropriate solutions. NCRST-I's approach has been to explore everything that new technologies offer and to develop products that come much closer to meeting the needs of the transportation community (see Figure 1).

As the lead site of NCRST-I, the University of California at Santa Barbara is also the home of the Alexandria Digital Library, a leader in specialized applications of digital library technology to geospatial data. Products that integrate GIS with digital library technology and search engines are just beginning to appear in the GIS world. In addition, NCRST-I is actively developing another component of this integrated approach to remote sensing data management: a comprehensive data model for transportation applications. The data model, termed UNETRANS, is being developed with the help of addi-

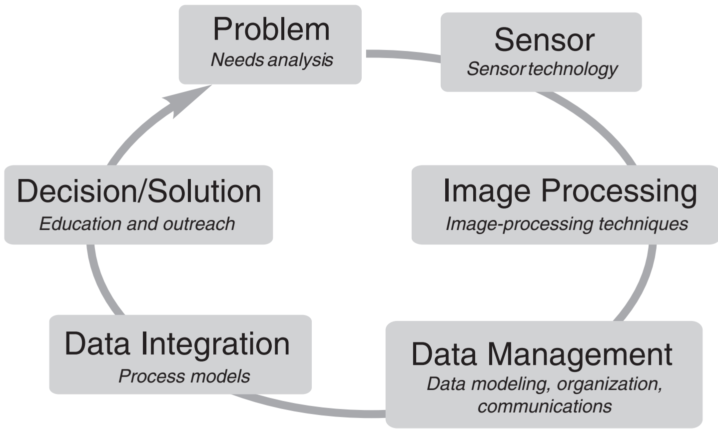


**FIGURE 1 Remote sensing in the context of transportation information requirements.**

tional funding from the Environmental Systems Research Institute (ESRI), a leading GIS vendor.

## Consortium Research Projects

### *Road Feature Inventory*

Many inventory data collection methods are used by transportation agencies in the United States, but they are often time-consuming and labor-intensive. With data requirements increasing, more efficient methods of data collection are needed. A pilot study was conducted to evaluate the use of remotely sensed images for the collection of roadway inventory features. Images at resolutions of 2, 6, and 24 in. and 1 m were evaluated and compared for the study area. Imagery was tested for positional accuracy, the number of inventory features that could consistently be identified, distance measurements, and variation among users in correctly positioning feature location.

A root-mean-square (RMS) test was used to evaluate positional accuracy with kinematic Global Positioning System (GPS) points (centimeter accuracy) for comparison. The 2-, 6-, and 24-in. data sets met the accuracy requirements for anchor points, according to the Iowa DOT linear referencing system (LRS) specifications of ±1 m RMS. The 1-m data set did not.

Even if there are standard procedures for identification of a feature and selection of its location, there can be differences among observers in locating the same point. Nine different features—signals, utility poles, drainage structures, medians, pedestrian crossings, intersection centers, railroad crossings, bridges, and driveways—with a sample size of five or six elements were randomly selected in a pilot study area. Observers familiar with ArcView were selected to identify and locate each set of features in each data set. Only three of the nine features could visually be identified in the 24-in. and 1-m images.

The utility of imagery was evaluated for creation of anchor sections. Distance measurements from the photos were compared with videolog van distance measuring instrument (DMI) measurements. None of the photo-based measurements met the requirements for anchor sections in the Iowa DOT LRS. However, these requirements are stringent, and financial constraints may require that standards be lowered.

In conclusion, although lower-resolution images are more cost-effective, their usefulness is limited by the user's ability to see and identify inventory features. A significant number of features either could not be identified or could not be regularly identified in the 1-m and 24-in. data sets. Because the ability to consistently identify features decreases with lower resolution, images with at least 6-in. resolution would be necessary for most inventory purposes. For collection of data elements for the LRS datum, 2- or 6-in. resolution would be feasible if datum accuracy standards were relaxed slightly.

### *Centerline Extraction—Manual and Automated*

With GPS now a popular accessory in numerous systems, a need is emerging for a new generation of centerline databases that are more detailed, accurate, up to date, and universal in coverage than the current products (see Figure 2). In August 2001 a gathering of international experts on centerlines was hosted by NCRST-I. What emerged in parallel with a wide variety of approaches—pavement signatures, edge detection, GPS, and futuristic ITS scenarios—was that centerlines fulfill such a variety of roles, with accuracy demands from centimeters to

**FIGURE 2 Centerlines derived by manual digitizing.**

decameters, that remote sensing is best viewed in concert with other technologies. Centerlines have different uses and therefore different specifications; some data are required faster, others cheaper or better. The techniques applicable for mapping relatively large areas on a scale of 1:50,000 from Landsat7 imagery are entirely different from those for urban street mapping from low-altitude photography or hyperspectral sensors. Remote sensing holds the greatest edge in the development of global transportation databases useful to international economic analysis and disaster relief.

Our approach to centerline detection is based on manual digitizing and semi-automated extraction from hyperspectral imagery. The manual digitizing project focuses on the accuracy of imagery required for corresponding accuracy in centerlines, in both two-dimensional horizontal geometry and linear measurement. The hyperspectral project has focused on developing a spectral library of construction materials with a field spectrometer to gather several hundred samples of asphalt, concrete, road striping paints of various colors, and other surfaces with similar spectral signatures, such as composite roof shingles. With principal component analysis, signatures were clustered into logical groupings and identified as spectral regions where the best discrimination between materials could be achieved. The results showed that the technology holds promise not only in identifying road material, but also in identifying age and, in broad terms, road condition.

### *Centerlines from GPS*

Remote sensing can also be used to validate centerlines derived from other sources. GPS data are increasingly associated with pavement condition surveys, and the GPS data can be mined independently from the surface condition data for development of centerline maps. There are situations in which the vehicle trajectory is not well documented in metadata (e.g., which lane). On winding roads, the 1- to 2-Hz sampling rate of GPS may be too coarse to produce accurate linear measures, whereas on straight sections, error in each GPS observation can be compounded to increase the apparent linear measure of the centerline. Processes are being investigated that may be applied to GPS-derived centerlines to improve accuracy. Imagery underlays provide the ground truth for the validity of these processes.

### *Bridge Location*

The National Bridge Inventory mandates that states maintain accurate records on bridge location. Current databases are in some cases rudimentary, with locations stated in cryptic and ambiguous textual terms. When these descriptions are translated into map locations, they can be in error by hundreds of meters. BridgeView, an extension of the popular ArcView GIS software, was developed to assist DOTs in their task of improving bridge location records. The user hones in on a bridge using imagery at various scales, from state to local. At the largest scale, orthophotos are overlaid with road centerlines and bridge locations from existing records, and errors can be detected and adjustments made. Clearly, with appropriate imagery resources, BridgeView's utility can be extended to DOT assets across all transportation modes, such as transshipment facilities, bus stops, and traffic control objects such as pedestrian crossings.

### *Airport Surveys*

Federal law requires that airports have comprehensive layout plans and three-dimensional (3-D) approach plans. Layout plans include 3-D models of airport buildings and structures, which enable analysis of runway visibility from the control tower. Light detecting and ranging (LIDAR), or laser scanning, is a promising technology for this task. Survey accuracy has been achieved in the ±10- to15-cm range. Through fusing digital camera photography with LIDAR data, 3-D Airport Layout Plans were constructed for the airport at Plant City, Florida. The same data were used to analyze the airspace and to identify potential obstructions to flight paths. This research project focused on both application requirements and appropriate survey procedures.

## Future Projects

As the project matures from data extraction to integration and decision support, new projects are developing in modeling and optimization.

### *Corridor Location*

Decisions on priorities for new infrastructure projects and alignment of new transport corridors involve many stakeholders with competing interests. It is critical that the right information inputs be identified and be made available to all interested parties and decision makers and that appropriate analytical and modeling tools be deployed. A new project, by the National Aeronautics and Space Administration's Stennis Space Center in the United States and the Commonwealth Scientific and Industrial Research Institute–Quantm in Australia, is being developed in this area, building on previous work and products.

### *Communications Infrastructure*

New towers for radio, cellular, and ITS-related communications need to be placed to maximize coverage for a given budget, and placement must be sensitive to environmental concerns. A new project is using data derived from remote sensing to determine optimal sites.

### *Infrastructure Security*

Hazards and safety issues have been an area of interest in the NCRST-I consortium, particularly appropriate design of infrastructure to ensure traveler safety, physical security of the infrastructure, and postevent survey of damage. The University of Florida was involved in laser scanning from aerial and ground platforms of the World Trade Center and Pentagon in the aftermath of the disasters of September 11, 2001. A number of other projects are being developed by consortium members in this area.

## Consortium Outreach

The consortium has several outreach activities under way. A growing set of resources on the web includes glossaries of technical terms in transportation, GIS for Transportation (GIS-T), and remote sensing, and an extensive bibliography with about 700 entries. In work being done in conjunction with the National Center for Geographic Information and Analysis' core curriculum in GIScience and the Remote Sensing Core Curriculum, a curriculum is being built on GIS-T and Remote Sensing for Transportation (RS-T). Regional meetings are being organized with state DOTs and local government agencies to promote remote sensing technology, offer technical advice, and facilitate local initiatives.

## Technology Application Projects

Two technology application project partners—Orbital Imaging Corporation (ORBIMAGE) and Tetra Tech Inc.—are nearing completion of their projects. Two others, Florida DOT and the University of Massachusetts, are beginning.

### *Orbital Imaging Corporation*

Orbital Imaging in Dulles, Virginia, and its partners, Parsons Brinckerhoff and Bentley Systems, are in the final stages of an agreement with USDOT to investigate and demonstrate the application of remotely sensed data to planning projects involving five transportation types: roads, railroads, airports, water ports, and transmission systems. The project's application of road data will be interactive with Bentley's MicroStation software. The demonstration will incorporate various forms of imagery and GIS data, with emphasis on nearly automated techniques for the delivery of remotely sensed digital imagery to desktops and software environments of transportation professionals. High-resolution imagery containing important land features will be used in demonstrating a number of effective applications for regional transportation planning. Northern Virginia is the geographic focus for this project in cooperation with the Virginia DOT. Much aerial, satellite, and ground-based imagery, accurate road centerline vectors, and other GIS data already exist for this area. By utilizing these resources, the project team will focus on tailoring software applications and interacting with transportation planners in technical exchange meetings and demonstrations.

With the project's nearing completion, the team has focused application efforts of the transaction agreement on the Virginia DOT Route 1 Location Study (see Figure 3). With ArcView parcel data shape files combined with black-and-white and 24-bit color digital orthorectified


**FIGURE 3 Northern Virginia's US-1 project plan with digital 1-ft resolution orthophoto and ArcView Fairfax County parcel information. The instant imagery access button is shown.**

images, the team is demonstrating the ability to quickly obtain remote-sensed data from geographically diverse server locations, integrate these data with infrastructure and demographic data, and display them at the user's desktop. Vector data coordinates are automatically matched to underlying imagery; relevant imagery is autoselected from the remote server based on the defined coordinate box. Implementation will initially serve Bentley's MicroStation software environments. This image server and software architecture eliminate on-site storage of massive image data libraries by removing image bank maintenance responsibilities from regional DOT or contractor personnel and by matching the location and resolution of accessible images to the vector map display view.

Remaining milestones include demonstration of the agreement's achievements to USDOT, the Virginia DOT, and selected contractors; presentations at numerous transportation infrastructure conferences and symposiums; and obtaining feedback from the presentations on the product's utility. Ultimately, an implementation plan and blueprint for future actions will be generated to help guide local, state, and federal initiatives.

### *Tetra Tech Inc.*

The project's focus is to develop remote sensing tools for analysis of federal intermodal connectors to the federal highway system. An intermodal connector is a major arterial on which trucks move from intermodal facilities such as railroad yards to the highway system. The test locale for this program is the Alameda Corridor area of southern Los Angeles County. The Alameda Corridor is a $2.8 billion freight rail system that connects the ports of Los Angeles and Long Beach, collectively the largest port complex in the United States, with the intercontinental rail system.

The project is analyzing two intermodal connectors. This first is Sepulveda Boulevard linking the port of Los Angeles' Intermodal Container Transfer Facility to the 710 Freeway. The 710 Freeway, in turn, links the ports with the regional highway system. The second is Washington Boulevard, which is part of a four-arterial (with Atlantic, Bandini, and Sheila Streets) intermodal connector that links Union Pacific and the Burlington Northern Santa Fe's rail facilities to the 710 Freeway.

The analysis is overseen by Tetra Tech, Inc., a nationwide infrastructure, environmental, and telecommunications firm based in Pasadena, California. The primary technical work is being conducted at Pasadena's Jet Propulsion Laboratory (JPL) and is supported by a multidisciplinary team of private firms, nonprofit research organizations, and local universities. The team is assessing the application of multiple remote sensing imagery types, including data from IKONOS, Landsat, and AVIRIS, to determine the images' value and their ability to be combined for greater analytical utility. To optimize their resolution, these data types are being refined with specialized enhancement techniques by the JPL. The data are being cross-referenced with digital orthophotography (provided by HJW GeoSpatial and California State University's remote sensing department) and then being integrated with an ESRI GIS platform.

Nationally available transportation and census databases will be integrated into these data to create analytical tools with national applications. As it is being accomplished, the work is being assessed by a team of industry experts led by the North American Foreign Trade Association (NAFTA) Corridor Institute and American Transportation Management, who will apply the tools to industry-specific needs. These applications include

- Planning of real estate along the intermodal connectors for expansion and optimization of goods movement through the intermodal connectors;
- Identification of trucks operating on surface streets in areas surrounding the intermodal connector study areas; and
- Identification of container depots in the neighborhood of intermodal connectors.

The tools will then be applied to public needs through USDOT, state transportation agencies, metropolitan planning organizations, and the national offices of Tetra Tech, to further refine them for national use.

### *Florida Department of Transportation*

The Florida DOT Transportation Statistics Office and its project partners, the Oak Ridge National Laboratory, Southern Resources Mapping of Miami, and TRANSMAP of Ohio, are teaming up on the USDOT's Research and Special Projects Administration project, entitled Highway Feature and Characteristics Database Development Using Commercial Remote Sensing Technologies, Combined with Mobile Mapping, GIS, and GPS. The major objective of this effort is to determine the feasibility of using commercial remote sensing technologies, combined with GIS, mobile mapping, and GPS, to develop accurate and comprehensive databases of roadway features and characteristics for infrastructure management.

The project will first use remotely sensed data—specifically, airborne and satellite high-resolution images—to extract highway networks (centerlines, edges, and medians); measure highway width and length; count traffic lanes; identify pavement types and road conditions; and obtain 3-D representation of highway systems. The project will also fuse remotely sensed data with commercial mobile mapping capabilities to map detailed roadway features and characteristics such as traffic signs, traffic control devices, shoulder types, pavement conditions, road names, and other roadway features. Existing GIS databases will be referenced for data comparison and feature attributes. Field GPS surveys will be performed to acquire ground truth data to validate data derived from remote sensing and mobile mapping or from existing GIS databases.

For study sites, the project will select a route section on I-10 between Jacksonville and Tallahassee and some local road segments in Tallahassee, all in Florida. It will run an operational test of the proposed approaches with the aim of generating the following results:

- An accurate and comprehensive Roadway Characteristics Inventory for selected study road sections that meets Florida DOT's production requirements;
- A technical report that documents the commercial remote sensing products, implementation procedures, and technical approaches used in the project;
- An assessment of the practical applicability of the proposed technologies—cost-effectiveness, accuracy, fitness, and ease of implementation;
- Recommendations on possible large-scale implementation; and
- Feedback to the research and industry communities for future technological enhancement.

Containing roadway features such as road edge lines, centerlines, guardrails, light poles, and road signs, the map in Figure 4 exemplifies the data in the Roadway Characteristics Inventory.

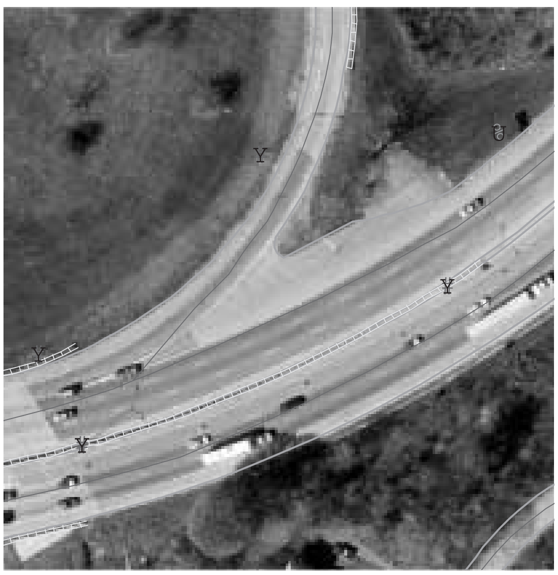

**FIGURE 4 Road feature map generated for the Roadway Characteristics Inventory.**

## *University of Massachusetts, Amherst*

"The Central Artery/Tunnel [CA/T] Project is about mobility, the environment, and economic growth for Boston and all of New England. When the project is finished in 2004, the quality of life in downtown Boston will improve dramatically" (www.bigdig.com/thtml/future.htm, April 10, 2001). All transportation public works projects are, at least in planning and theory, about improving mobility and quality of life. This project is about providing one method for measuring this improvement. With a project as large as the CA/T, standard techniques are usually inadequate to effectively evaluate changes that result from it. Particularly with infrastructure that has affected a region over several decades, as with the Central Artery and now the CA/T, changes over time may be dramatic or subtle but are often difficult to quantify. With the availability of wide-area imagery and the ability to analyze such imagery with expanded and improved spatial analysis techniques, new methods are available for measuring, and thus evaluating, changes that have occurred or are taking place around infrastructure projects.

Three change detection activities will be established for measuring change, including highway infrastructure, transit infrastructure, and land use or coverage. The ultimate goal is to provide the oversight agency (in this case, MassPike) with a tool or tools to assess change:

- Product 1 will use historical and current high-resolution remotely sensed imagery to detect and analyze changes in the highway infrastructure preceding the Central Artery in the 1950s to the current stage of construction of the I-90 and I-93 CA/T project. Because of Boston's highly intermodal nature, public transportation activities are a key feature of the overall transportation infrastructure. Several transit facilities are a part of or are directly affected by the CA/T.
- Product 2 will use historical and current high-resolution remotely sensed imagery to detect and analyze changes in the transit infrastructure associated with the CA/T from the mid-1960s to the current stage of construction of the South Boston Transitway, the Silver Line–Bus Rapid Transit Initiative, commuter rail, the heavy rail maintenance yard, the Amtrak Acela High-Speed Rail terminus, and associated Boston Harbor ferries.
- Product 3 will use historical land use classification maps and current GIS land use databases from interpretation of high-resolution imagery to document and analyze transportation-related land uses over time for the CA/T project. To provide a meaningful level (i.e., of Level IV, L4-U.S. Geological Survey) of evaluation for land use, an overlay of a spatial land use classification layer, as shown in Figure 5, will be used. In this figure, the classification is from 1991, and the imagery was taken in 1999. In an example of change, the Ted Williams Tun-


**FIGURE 5 Land use classification in the vicinity of the Boston Central/Artery Tunnel Project.**

nel entrance was classified as urban open and is now considered a transportation facility.

## Concluding Remarks

The management of transportation assets requires fast and easy access to appropriate data, particularly data on location and change. Remote sensing is an excellent source of such data, and several NCRST-I projects have demonstrated the role that imagery can play in this regard. However, all too often demonstrations of capability fail to lead to actual implementation. We believe that implementation requires more than a basic demonstration of capability; it also requires

- Ready access to tools that implement solutions in easy-to-use packages; and
- Tools that address all stages of dissemination of remotely sensed data, including data models, digital libraries, and search engines that are fully integrated with applications.

Many of these tools will be demonstrated at this conference, and many more are under development and will be made available in due course through the NCRST-I website.

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## Moderator Summary

### *John J. Conrad*

I am Assistant Secretary for Engineering and Regional Operations with the Washington State Department of Transportation (WSDOT). My job here is to provide observations on the current state of remote sensing applications for transportation infrastructure and engineering and on future contributions that these technologies could make.

I wasn't here last year, so I am a fresh observer and a fresh participant. I want to take a step back and put a larger context around this from the standpoint of a DOT. It will be that of WSDOT, but I think our experiences are very similar to those of DOTs all across the country in the face of the changing dynamics in the world we are involved in.

First, DOTs have a high turnover of their chief administrative officers. We have just turned over, in our department, from one person that was there for 8 years, but the average lifespan of the head of a DOT now is somewhere between 2 and 3 years. So, there is almost a continual upheaval in DOTs across the country as they experience new leadership, and new leadership brings new ideas and new ways of doing business. That certainly is what we are undergoing right now at WSDOT with a very dynamic leader with lots of new ideas and lots of involvement in the department's detailed operations.

We are operating in an environment in which people expect us to be more efficient. All of our customers and the taxpayers have very high expectations of us. The fortunate thing is that we have a product that everybody wants, so we are in demand. However, we are also playing in a market in which our revenues are relatively stagnant or, in many cases, shrinking. We are operating systems that are mature and are aging, and in fact, we are now back to the stage of having to rehabilitate many of the parts of our transportation system that were constructed back in the 1950s, 1960s, and even in the 1970s. We are not constructing a whole lot of new facilities these days, but many of us have high hopes, as you saw in Elizabeth Lanzer's presentation this morning on the 405 Corridor (see pages 19 and 78).

No matter the dynamics that we're operating in, we are still in a world where we are planning, designing, building, maintaining, and operating transportation facilities. You can combine the planning and the design as a part of the build, or at least for my purposes here, but we expect to do it in a fashion that treads lightly on the environment or enhances the environment to make up for some of the sins of our ancestors. When I say "some of the sins of our ancestors," we can talk about things that were done when the system was first built. In the case of the endangered species listing of the salmon stocks in the state of Washington, we are going back 150 years to see generations of actions that have led us to where we are today. The things we do as part of our transportation projects are very small, incremental measures that help with the endangered species listing. We are certainly not going to be able to easily overcome 150 years of mankind's efforts to get rid of that species.

I hope, as I lay that context out, that you can begin to see how some of the presentations today fit in with those challenges that we are faced with. One of these, as just mentioned by Shauna Hallmark, is that we need to find ways to absolutely keep our staff off the road as much as possible. For the purposes of work zone safety, whether it be for a construction project, a maintenance project, or people out there doing data collection, any way that reduces exposure is great.

From the building standpoint, our challenge is to do it on time and on budget. The project development process takes years and years, and we are looking for ways of environmental streamlining. We are looking for ways to do context-sensitive design—to come up with facilities that fit better into the communities in which they are located. We are also looking for ways to enhance the environment as a part of our work.

Maintaining and preserving our system are a huge challenge, because of the system's age. Val Noronha has talked about bridges and pavements, and I'm struggling a bit there. For example, with pavements and bridges, we have extensive management systems for both of those parts of our infrastructure. For pavements, we are out there every year. We are not concerned particularly about the age of the pavement, as much as we are concerned with its condition. We are looking at things such as What is cracking? How smooth is the pavement? Is it rutted? How long has it been lasting? We then use that information to program when we are going to replace those pavements.

On the bridge side, we have our own series of acronyms, and a couple weeks ago I went out with our bridge preservation crew and took a ride in the UBIT. UBIT is an under-bridge inspection truck. We have people out there on a continuing basis, crawling under, through, and around our bridges, assessing their condition. I have to admit that I snickered a bit when I learned that one of these projects was to tie down where our bridges really are, and, lo and behold, I found out that in some cases, our bridges are just like the ones shown in that slide—they are about 50 ft from where we thought they were. So we need to take that a little more seriously than I originally thought. But we do have extensive inventories in management systems, and we are looking for ways to feed those inventories and those management systems in a less expensive and more efficient way.

Intermodal connections are another big issue we deal with in Washington with the ports of Seattle and Tacoma, and this includes the connectivity between the ports and the highway system and between the ports and the rail system, and how the rail system and highway system interrelate.

A new concern that we did not pay much attention to until September 11th, although we had our issues from time to time, is security and vulnerability assessments of our facilities. It is something we are all just scratching the surface of now, trying to figure out what it is that we need to do and how to do it. Perhaps there is an application for remote sensing as a part of that.

In the future, I guess we are looking for ways to do things that we have not thought about. I can't tell you what they are, because I haven't thought about them. Most of what we looked at today is finding different ways to do what we are doing right now. I think we need to be a little more visionary in our thinking in the years ahead.

I think technology transfer and delivery mechanisms are going to be a big issue as we move ahead with this technology. I will save my comments there, and I think it is more appropriate to talk about it in the wrap-up session.

I am giving you the perspective from a DOT, but we are not the only transportation agency or agencies that have transportation facilities out there, and I think local agencies in cities and counties are big customers as well.

In listening to the presentations, I liked the approach of trying to compare existing processes and measure the differences in cost, cost-effectiveness, life-cycle costs, and so on. Perhaps the biggest challenge is going to be, in the old gambler movie lingo, knowing when to hold them and when to fold them. I think that will be a challenge for several of these technologies: at what point do you decide "Yes, this is good, and let's go with it," or keep going with it, or "No, this isn't going to work, and we should let go and move on to something else"?

Common specifications will be crucial. This is an issue that DOTs have been dealing with for several years in relation to ITS, as we try to have a common framework or a common specification for what is being developed. It is very difficult to implement a technology without a common specification.

One important thing that was not specifically brought out in the presentations, but was discussed in the write-up on infrastructure, is organizing regional meetings with DOTs and local agencies to help promote remote sensing technology and seek to provide technical advice and facilitate local initiatives. I cannot stress enough the importance of maintaining that contact with all the users or as many users as you can and making sure they are onboard and giving you that reality check as you move ahead with these projects.

Session 5

# Transportation Lifelines and Hazards

## Overview of Remote Sensing Products and Results

Stanley A. Morain, *University of New Mexico*
Walter H. Kraft, *PB Farradyne Inc., Moderator*

### Safety, Hazards, and Disaster Assessment: Consortium Paper Presentation

*Stanley A. Morain*

In 2000 the U.S. Department of Transportation (USDOT) and the National Aeronautics and Space Administration (NASA) inaugurated a new joint program titled the National Consortium for Remote Sensing in Transportation (NCRST). Four university consortia were established in the United States to focus on specific sectors of transportation-related issues. The consortium described here—NCRST–Hazards (NCRST-H)—focuses on transportation safety, hazards, and disaster assessments. It consists of the University of New Mexico's Earth Data Analysis Center (EDAC); the University of Utah Geography Department's Center for Natural and Technological Hazards (CNTH) and its Digitally Integrated Geographic Information Technologies (DIGIT) Lab; George Washington University's Space Policy Institute (SPI); Oak Ridge National Laboratory's (ORNL's) Center for Transportation Analysis (CTA); and the University of Calgary's Department of Geomatics Engineering. There are also three commercial partners. Two are engaged in pipeline leak detection and hazards assessment: Aeris, Inc., and DigitalGlobe (formerly, EarthWatch, Inc.). The third, ImageCat Inc., is engaged in earthquake damage assessments with synthetic aperture radar (SAR) imagery.

#### NCRST-H Focus Definitions

Transportation safety, hazards, and disaster assessment embrace topics that are not as intuitive as the subject matters for the other consortia. NCRST-H's interests focus on assessing the lifelines themselves and their corridor alignments, not so much on what travels along them. These lifelines include roads of all classes, railroads, bridges, airports, pipelines, coastal and inland waterways, marine facilities, and intermodal facilities.

Assessments for safety, in this context, refer to failures in pipelines and bridges, road washouts, track misalignments, waterway morphology, airport runway and glide-slope obstructions, road subsidence, and intermodal disruptions; however, they do not refer to passenger safety as related to, say, safety belts or tire safety (see Figure 1). The chief criterion is whether the phenomenon can be remotely sensed. Interest is centered on aerial and satellite imaging, light detection and ranging (LIDAR), radar, interferometric SAR (IFSAR), and hyperspectral sensing. Where possible, there is a need to integrate in situ sensors and related data sets into intelligent transportation systems (ITS).

Hazards refer to

- All safety issues caused by natural means, such as floods, fire, land subsidence, and avalanches;
- Technical hazards such as those associated with waste transport and pipeline failures that may require evacuation or emergency relief; and
- Terrorist actions that disrupt any mode of common transportation.

Here, again, the chief criterion is our ability to provide timely imagery, maps, and sensor data for planning and mitigation—as was the case for the Cerro Grande fire in Los Alamos, New Mexico.

**FIGURE 1 Subsidence and flooding are typical hazards for transportation lifelines, as shown by this composite of photographs.**

Disasters refer more to "acts of God," as they are referred to in the insurance business. Thanks to NASA and the National Oceanographic and Atmospheric Administration, remote sensing technology is advancing our ability to forecast disastrous events and thus improving the public's avoidance and mitigation responses. Such events include network disruptions caused by hurricanes, floods, tornados, volcanoes, fires, dust storms, and earthquakes. NCRST-H is not involved with predicting or forecasting these events per se, because that is the job of the weather and geophysical sciences; rather, it is interested in the transportation consequences arising from these events. For example, ImageCat, Inc. is developing a SAR-based interpretation system for assessing the damage to lifeline infrastructures resulting from these natural phenomena.

The disastrous events of September 11th have chiseled indelible new instructions for NCRST-H that will be pursued in its third year of operation. GI-Science can contribute to homeland security, but there are many challenges that must be considered and articulated. However, if ways and means can be identified for using remote sensing and geospatial technologies for assessing and mitigating terrorist acts, it will improve substantially the near-real-time information extraction capabilities required by other, more predictable events.

## Consortium Tasks

Tasks in the first and second years of consortium operation have considered these broader definitions, while focusing attention on specific applications research. The consortium's ORNL members at CTA have focused on perfecting an image-based automatic road extraction technique and on testing their evacuation modeling system. The University of Utah CNTH and DIGITLab have been creating a transportation lifeline database for Salt Lake City focused on avalanche hazards. They have also been developing hyperspectral data applications to assess road composition and condition and IFSAR applications for road subsidence. The University of Calgary is a recent addition to the consortium and is focusing its initial activities on pipeline monitoring with LIDAR sensors. The SPI at George Washington University has assembled a bibliography of remote sensing for safety, hazards, and disaster assessments and developed a technique for assessing hazardous rural road segments from imagery. The University of New Mexico's EDAC has been assessing high-resolution satellite imagery for Enhanced 911 (E911) updates and, on behalf of the consortium, has also inaugurated an airport glide-slope safety initiative involving three commercial partners and the city of Santa Barbara, California. It is also developing an application that integrates satellite remote sensing data with geographic information system (GIS) road networks and merged, real-time Doppler radar weather data to identify hazardous conditions on unpaved rural roads.

The consortium, overall, has been actively developing application briefs, technology notes, and cookbooks (on display at this conference) and since last summer has undertaken several international activities to extend outreach and technology transfer in Germany and China.

## Technology Application Partners

Two of the technology demonstration contractors are focused on oil and gas pipeline monitoring and spill remediation. The Aeris team consists of Aeris, Inc.; System Planning Corporation; Summit Helicopters; and SAIC. The DigitalGlobe team consists of DigitalGlobe; Pacific

Gas & Electric; Lawrence Livermore National Laboratory, and Chevron.

The Aeris team's objectives are

- Collecting airborne ground penetrating radar (GPR) data of a simulated pipeline failure by means of a multifrequency, dual-polarized radar system with different viewing geometries and distances (see Figure 2);
- Improving large-area detection using GPR;
- Assessing early detection of pipeline leaks;
- Supporting optimization routing for new pipelines; and
- Assessing hyperspectral sensor capabilities.

DigitalGlobe's objectives are

- Interpreting and adapting IFSAR deformation mapping as input to risk analysis modeling;
- Interpreting and adapting high-resolution satellite environment maps;
- Determining reliability of IFSAR digital elevation models (DEMs) and resulting deformation maps;
- Validating multispectral environmental impact maps; and
- Automating and customizing interferometry processing.

## Status of Consortium Tasks

### *Automatic Road Extraction*

For road extraction, conventional techniques are labor-intensive and expensive. Automated techniques offer time and cost savings and greater reliability. The consortium's approach uses a pattern recognition algorithm that employs image attributes such as intensity, changes of intensity, texture, and neighborhood connectivity. These are used to define a road model. Potential roads are extracted by matching the model with the image (see Figure 3). A feature network is established to group road segments into a hypothetical road network. By comparing the characteristics of this network with the trained road model, valid candidates are identified.

**FIGURE 2 Helicopter-mounted GPR for assessing pipeline leaks.**

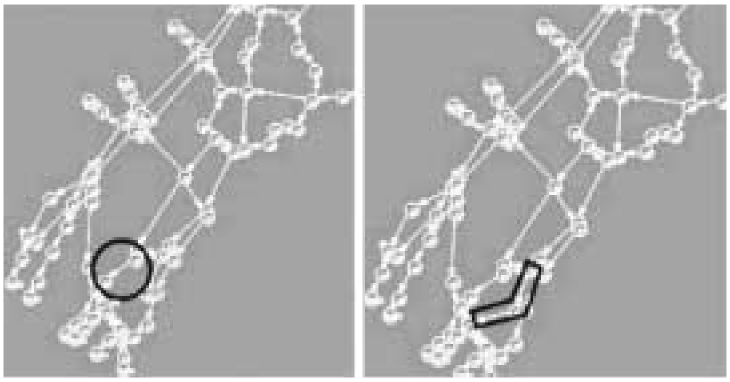
**FIGURE 3 Automatic road extraction by means of image attributes and neighborhood connectivity.**

### *Evacuation Modeling*

The evacuation modeling team is perfecting the input data sets required to interface the Oak Ridge Evacuation Model (OREMS) with ARC/Info. So far, model runs for the Sequoya Nuclear Power Station in Hamilton County, Tennessee, have verified the model's robustness and have revealed the relative importance of parameter inputs. In one case, where a road was out of service during an emergency, nighttime evacuation of 95% of the people took 3.2 h (Figure 4*a*). In a second case (Figure 4*b*), the model changed the direction of traffic flow along a key artery to expedite evacuation to achieve a 95% evacuation in less than 3 h.

### *Trafficability on Rural Roads*

The trafficability task assesses the role of imagery in identifying hazardous road segments on unpaved roads in remote areas. This is an important task with numerous applications in both the military and civilian environments, but before they can be considered useful and reliable, the image data must be registered geospatially with associated geophysical data. Soil, topography, and geology have been merged with aerial photography to delineate road nets at Hopi, Arizona, and in McKinley County, New Mexico. The road network has been superimposed, and the output looks promising for planning and road maintenance. Road segments have been identified with high potential risk during inclement weather. The next steps are to verify and validate the results and to develop a user guide describing procedures, costs and benefits, and future technologies.

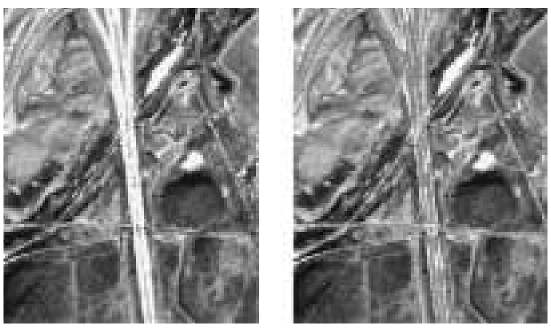


(a) (b)

**FIGURE 4 Two modeled scenarios for the Oak Ridge Evacuation Model: (*a*) road closure scenario evacuated 50% of the population in 1 h, 75% in 1.8 h, and 95% in 3.2 h; (*b*) road reversal scenario evacuated 50% in 1 h, 75% in 1.75 h, and 95% in 2.8 h.**

### *Searchable Remote Sensing Database*

For the searchable database, citations and abstracts have been captured for more than 1,800 English language items that link remote sensing and GIS technologies to the general categories of safety, hazards, and disaster assessment. Only a small number of these references relate to transportation, but the database represents a tool that can be shared for practical applications and for assessing remote sensing methods. The next steps in this task are to review the database for those citations that relate specifically to remote sensing transportation issues and to organize relevant entries by sensor type and application to develop technology assessments. Preliminary work by Aeris, Inc., indicates that road surfaces exhibit spectral differences related to paving material and condition (see Figure 5). The meaning of these differences will be assessed in the context of road maintenance.



(a) (b)

**FIGURE 5 Comparison of (*a*) hyperspectral characterization of road surfaces with their (*b*) monospectral (panchromatic) appearance. Colors in the original image show different paving materials and surface conditions that can affect road safety. (Courtesy of Aeris, Inc.)**

### *Lifeline Vulnerability*

The goal in the lifeline hazard task is to assess advanced remote sensing data sets as inputs to changing transportation vulnerabilities. These vulnerabilities can relate to the lifeline itself or to regions through which the lifeline passes (e.g., canyons prone to avalanches or slowly changing conditions along the corridor). For avalanches, the conceptual and mathematical frameworks have been developed, and an application brief has been prepared (see Figure 6). With ARC/Info, a prototype spatial database has been built for the Salt Lake City area that includes major roads, rail, pipelines, and transmission lines. Hyperspectral analysis of road surfaces has been initiated. The methods should next be applied to actual hazards in the Salt Lake City area. More hazard maps need to be incorporated into the lifeline database so the database can be used to model threats to transportation lifelines. A user guide and workshop materials for IFSAR, hyperspectral, and high-resolution imagery are being developed.

**FIGURE 6 PG&E pipeline showing encroachment of neighborhoods inside the 1-km buffer.**

### *Lifeline Subsidence*

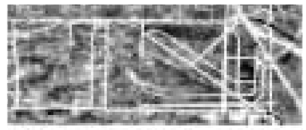
Work with ERS-1 and -2 satellite data, TOPSAR, and AirSAR is under way for measuring the impact of ground subsidence on roads, bridges, railroads, and pipelines. The goal for evaluating IFSAR is to produce topographic and displacement maps to evaluate lifeline loss due to slope-induced subsidence failures. The results so far are that two ERS-1 SAR scenes of Salt Lake Valley have been processed into interferograms. The pair produced good fringes in the valley, representing the topographic contribution to the phase shift. In the next steps the topographic component in the interferograms will be removed to obtain the signal due to ground subsidence. An analysis will compare slope maps generated from the fused DEMs, which will pave the way for evaluating DEM resolution on hazard mapping (see Figure 7).

### *Enhanced 911 Emergency Response*

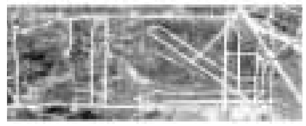
For the E911 task, the goal is to compare digital orthophotoquads, IRS-C, and IKONOS data sets for updating road networks in urban fringes and rapidly growing bedroom communities (see Figure 8). The methodology has been as follows:

- Select test sites.
- Acquire imagery and vector road layers.
- Process the imagery (geocorrection, merging, and enhancement).

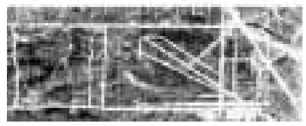
**FIGURE 7 Fusion of ERS-2 satellite data (the background image) with ERS-1 data taken 3 years earlier (interferogram), both superimposed on TM 30-m data sharpened with SPOT 10-m panchromatic data. The interferogram shows an area of subsidence (at the millimeter level) near Las Vegas, Nevada, caused by groundwater withdrawal during the 3-year interval. (From *Professional Surveyor,* Oct. 1999.)**



**(a)**



**(b)**



**(c)**

**FIGURE 8 Road updates from (*a*) DOQQ (0.33-m resolution); (*b*) IKONOS (1-m resolution); and (*c*) IRS-C (5-m resolution).**

- Perform an accuracy and cost assessment.
- Compare the cost per kilometer of road updated.
- Verify and validate the results.

So far, the results suggest that IRS-C data represent the best value and provide a medium-priced data set for the maximum length of road per kilometer updated.

### *Airport Glide Slope Obstructions*

An exciting new development is in Figure 9: a LIDAR image showing the glide slope to an airport runway through which tree crown obstructions have protruded.

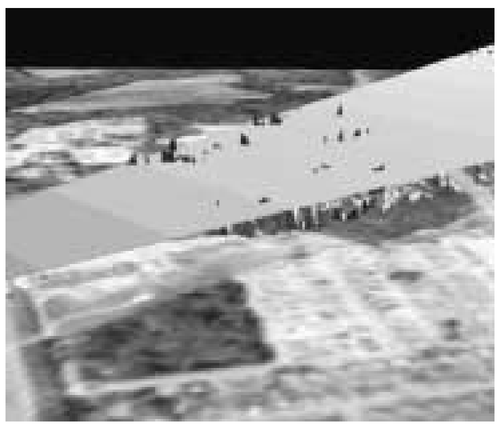


**FIGURE 9 Runway glide slope (*gray swath*) showing trees penetrating above the path. Heights of trees and other obstructions are obtained from airborne LIDAR measurements.**

In 2000 the U.S. Congress passed the Ron Brown Airfield Initiative to survey glide slope obstructions on the approaches to some 7,200 airports in the United States and an undetermined number of airports worldwide. In October 2001 NCRST-H inaugurated a joint project with BAE Systems, Airborne-1, the Keith Companies, I. K. Curtis Services, and Bohannon–Huston to acquire LIDAR coverage, ground control, and aerial photography for the Santa Barbara, California, airport. The objective was to compare the costs and accuracy of the LIDAR solution with the costs and accuracy of more traditional aerial and ground survey solution. The obstruction identification surface extends for 13 km on each end of each runway. For these surfaces and a specified distance around the entire airport complex, the geolocation and surveyed heights of all objects that protrude above the obstruction identification surface—building, trees, light poles, antennas and towers, power lines, and other physical features—had to be recorded. Project collaborators are contributing human and financial resources in support of USDOT resources to complete this demonstration. Results will include a thorough report describing the process and product, as well as comparative time, costs, and accuracies in the context of standards of the Federal Aviation Administration and the National Imagery and Mapping Agency. The goal is to develop training materials that transfer the knowledge to airport managers and other authorities to assist their decision making.

## Current and Forthcoming Products

The consortium has been actively creating informational products for various transportation communities. At the senior executive level is a series of application briefs; at the senior technical level are technology notes and white papers; and at the technician level are cookbooks to guide the technology's adoption. As an additional service, instructional materials are being developed for presentation at workshops at future Transportation Research Board and related technical conferences. These materials are intended initially as hands-on experiences with canned data sets, but they can be modified under special arrangements to employ customized agency or user group data. The educational materials are being developed in association with Bergstralh–Shaw–Newman, Inc., leaders in the transportation education industry.

Figure 10 shows an array of application briefs. These are typically two-sided synopses of GI-Science technology applied to specific transportation issues. They are abstracted from longer technology notes, which range to several pages in length. The briefs may include technical backup from white papers that have been commissioned from experts in various remote sensing technologies. The white papers are typically more than 10 pages, with key references cited and several service providers listed. The consortium's long-term intention is to create collections of informational and how-to documentation that address both the technical and economic aspects of

**FIGURE 10 Sample information products developed by NCRST-H.**

**TABLE 1 Products Available from NCRST-H (as of December 2001)**

| Type of Document | Title | When Available |
|---|---|---|
| Application Brief | Avalanche Monitoring and Mitigation | 7/01 |
| Application Brief | Nuclear Power Plant Emergency Evacuation | 7/01 |
| Application Brief and Technical Note | Road Updating Using High-Resolution, Remotely Sensed Imagery | 7/01 |
| Application Brief, Technical Note, and Cookbook | Automated Road Network Extraction from High-Resolution Images | 7/01 |
| Application Brief, Technical Note, and White Paper | Automatic Feature Recognition and Extraction from Imagery | 11/01 |
| Application Brief and Technical Note | Road Mileage | 11/01 |
| Application Brief, Technical Note, and White Paper | LIDAR | 11/01 |
| Application Brief and Technical Note | Hyperspectral | 11/01 |
| White Paper | Remote Sensing Applications: Hyperspectral Imaging | 11/01 |

applications and to work with industry and government to put the technology to work.

The list of available and forthcoming documents is given in Table 1.

## Acknowledgment

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## Moderator Summary

### *Walter H. Kraft*

I am Walter Kraft. I'm a Traffic Engineer. I'm an ITS Engineer. I do planning. I do operations. I do management. I do integration. I want to see what is happening on the roadway.

Are all of you familiar with ITS—intelligent transportation systems? Do you know what it is? I like the definition that describes ITS as the use of information technology in transportation. ITS has been around a while, even though the term is relatively new. Any guesses as to when it was first used in this country? I believe ITS started in 1928 when the first actuated traffic controller was installed in Baltimore. ITS deals with the flow of information. We gather information, we look at it, we synthesize it, we do something with it, and we send information out. Let's draw a mental picture of ITS where information flows in, we do something with it, and we send information out. That is what the controller in Baltimore did. The controller left the green signal on the main street until information was received. When a car came to the side street, the driver honked the car's horn. A device had been placed there that heard the sound, which caused a change from a green signal on the main street to the side street. The controller had received information, did something with the information, and sent information out. The information it sent out caused the green signal to change from the main street to the side street. That is ITS, and I've been involved with ITS all my professional life.

I'm interested in remote sensing, because I want to see how we can provide information to maintain and improve mobility and also to improve safety on our roadway systems.

I get a little concerned because I do not think we are measuring the right things. I say that, because a number of years ago I wanted to submit a proposal to the Federal Transit Administration to determine if people would make a different modal choice if they had real-time information on travel conditions and the costs of travel. To do that, we needed to install detectors to measure travel time. A large firm that had developed a new detector contacted me. I asked the representative to tell me about the device. He said, "Do you realize that with our system we can detect where every nuclear submarine is located right now around the world?" I told him that I didn't care where every car is on our roadway system; all I wanted to determine was the average travel time of all the vehicles. They were giving me the wrong information. It is not what I wanted to measure. I didn't want to know where each car was. I wanted to measure travel time.

So, I'm concerned that we are going in the right direction. We need to reflect and ask if we are collecting the right information and if we are using it the right way.

I am encouraged by this meeting because last year I got frustrated. My frustration was that nobody would listen to me. When I said, "You're not providing what I need," I was told, "We can't do that." Right now, I think that gap has been reduced, and I'm encouraged by finding more topics on operations, which is the area I'm interested in.

I am encouraged by what I have heard, because as I listened to the different speakers, I had certain reactions as to how I would use remote sensing in an operations environment. With respect to lifeline disruptions, I would look beyond avalanches and think of anything that would affect the lifeline. Vehicular crashes affect the lifeline. Construction of facilities affects the lifeline. Soon we are going to be in a period of major reconstruction of our Interstate system. The reconstruction of many of the roads will take multiple years for completion. For I-95 in Palm Beach County, Florida, it will take 8 years to reconstruct a 10-mi section. It will take many years for reconstruction of the Woodrow Wilson Bridge here in Washington, D.C. The Katy Freeway in Houston will also take a number of years for reconstruction.

As I learn more about remote sensing, I find that I would like to know more about the effects of traffic disruptions on travel. There are dynamic impacts that I would like to know about. I would like to have real-time information. How do I find out what is happening on a real-time basis so that I can react to it on a real-time basis?

I would also like to know the impacts of diversions. Where are people diverting? How can I move traffic better? Again, this knowledge requires real-time feedback. Understanding travel impacts is a challenge that I will add to understanding avalanches.

I think that yesterday's discussion on airports was very interesting. I did not realize that tree growth is a problem for glide paths, because traffic operations also has a tree growth problem. If trees block a driver's view at intersections or if traffic control center operators cannot use a remote camera to view traffic disruptions because of tree growth, safety can be affected. So I see a lot of opportunity there for this technology.

The evacuation planning presentation was interesting, because I think there is a lot of good potential. When you analyze evacuation planning, you want to determine different ways of evacuating people. Evacuation planning for a nuclear power plant is generally straightforward because the plant does not move. Hurricanes are harder to plan evacuations for because hurricanes move and move unpredictably, so you have to plan dynamically and realize that conditions are going to change unpredictably over time. The challenge is: How do we monitor the unpredictable on a real-time basis?

I thought the presentation on mapping transportation risk was fantastic, because I see a lot of potential. If during the design process, I can locate areas where there might be accidents, I could change the design to minimize accidents at those locations before construction takes place. If the design cannot be changed, maybe I can locate remote television cameras at those locations to observe traffic and verify that an accident has taken place.

Earlier, mention was made of keeping pedestrians off high-speed roadways, which is very important in the arena of incident management. Let me share a statistic, which I thought was astonishing. For the period of 1992 to 1997, 31% of fatalities incurred by law enforcement personnel by event or exposure were attributed to highway crashes. That is astounding. Police are getting killed either in their vehicles or as they are managing an incident. Police are not the only responders to an incident. Fire, emergency, and department of transportation personnel also help manage an incident. We want to move all responders off the roadway as quickly as possible to save their lives. So, what can we do to get them off quickly? Right now, police usually put up a total station to reconstruct the accident scene. Can't we get this information from a satellite or from an airplane, so that the incident scene can be cleared more quickly? This is another challenge for you.

I helped develop a brochure for the Federal Highway Administration, which describes a self-assessment tool that an agency can use to evaluate its roadway operations. I brought the brochure to the conference because I think remote sensing can potentially be applied to help an agency gauge its activities. Again, there is a need that remote sensing may help fulfill. I encourage you to take a copy of the self-assessment brochure.

SESSION 6

# 10-Year Remote Sensing Industry Forecast

James R. Plasker, *American Society for Photogrammetry and Remote Sensing*[1]

In August 1999, the American Society for Photogrammetry and Remote Sensing (ASPRS) and the National Aeronautics and Space Administration (NASA) Commercial Remote Sensing Program entered into a 5-year Space Act Agreement to combine resources and expertise for

- Baselining the remote sensing industry (RSI);
- Developing a 10-year RSI market forecast;
- Providing improved information for decision makers; and
- Developing attendant processes.

The forecast participants were

- NASA,
- ASPRS,
- Space Imaging,
- Kodak,
- SPOT Image Corporation,
- EarthData,
- PAR Technology Corporation,
- Autometrics,
- Spencer Gross,
- American Forests,
- RAND Corporation,
- Pictometry International,
- Leading Edge,
- Lockheed Martin,
- Geomatics,
- University of Arizona,
- University of Utah,
- University of Southern Mississippi, and
- Rochester Institute of Technology.

Phase I of the survey, Characterization and Baseline Forecast of the Industry (December 2000), focused on the producer portion of the remote sensing process (see Figure 1). Phase II, Characterization of Customers/Users and Determination of Their Needs/Requirements, was completed in January 2002. Current summaries are available on the ASPRS website at http://www.asprs.org/news.html. Phases I and II are being documented, with publication anticipated in spring 2003 in the ASPRS journal, *Photogrammetric Engineering and Remote Sensing*. Phase III, titled Validating Phases I and II, will include a technology assessment and will be completed in December 2003. Phase IV, titled Market Forecast, will be completed in December 2004.

Phase I includes 36 interviews at the commercial chief executive officer (CEO) level; 437 web surveys of commercial, government, and academia personnel; 43 closed-envelope revenue surveys of commercial CEOs or chief financial officers, and a literature search.

To date, Phase II includes 134 interviews of managers and users; 4 focus groups involving members from the National State Geographic Information Council, local geographical information systems, ASPRS, the Management Association of Private Photogrammetric Surveyors, and the Urban and Regional Information Systems Association; more than 700 web surveys; and an ongoing closed-envelope revenue survey.

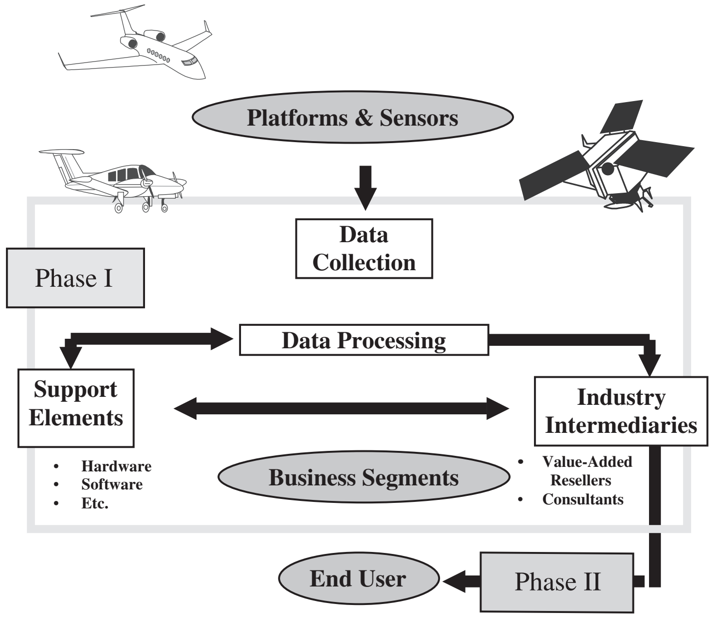


**FIGURE 1 Remote sensing industry definition.**

## Phase I: Industry Baseline

The baseline forecast, in constant 2000 U.S. dollars, showed a growth from \$1.8 billion in 2000 (actual) to \$3.3 billion in 2005 and \$6.0 billion in 2010.

In 2000, the largest market segments were divided as follows: 66% of respondents used aerial platforms, and the remaining 34% used space platforms.

In interviews, CEOs cited the following as barriers to growth:

- Technology. Innovations are needed for
  - –Increasing the speed of availability of information (rather than availability of data),
  - –Delivering information that will be valued by the user,
  - –Developing systems that integrate data and offer multidisciplinary solutions, and
  - –Lowering costs.
- Workforce education. The demand for entry-level personnel exceeds the supply.
- Customers' insufficient knowledge of remote sensing. Applications are based on the market, and demonstrations may help.

## Phase II: User Needs and Requirements

Of the 708 respondents to date, the government sector respondents constitute nearly half, or 47%, of the sample, with 34% of respondents from commercial accounts and 19% from academia. The survey identified three types of uses: data, information, and software. Data and information are used more than software. When the survey is completed, ASPRS plans to do a cross-cut analysis of the following factors:

- Demographic factors
  - –Sectors—commercial, academia, and government (federal versus local),
  - –Users versus managers,
  - –Tools needed versus tools used,
  - –Research and development,
  - –Education levels, and
  - –Training rates;
- Characteristics—imagery types, accuracy and resolution, timeliness, applications and market segments, collection means, coverage, data layers, and sources and providers.

Results of the surveys are presented in greater detail on the ASPRS website; however, the following are among the major findings from the preliminary survey results:

- A well-educated workforce exists, and the projected shortage is an issue of numbers.
- Approximately 60% of the respondents had taken course work related to remote sensing.
- The top three growth potential areas are in general mapping and environmental and civil government applications.
- In general, half of the user needs are being fairly well met, but a significant percentage of the needs, or 28%, are being poorly met. This is generally true across all sectors.

- Users of data and information collected from both aerial and space platforms agree that spatial resolution and geolocation accuracy are the most important characteristics.
- Cost is an important characteristic but not the most important. However, cost is an apparent major driver for managerial users who purchase the data and information.
- Increased elevation accuracy is needed.
- In the governmental sector, there is a decided need for elevation accuracy of approximately 3 m.
- Pending further analysis, there is an apparent general need for geolocation accuracy of 1 m or better.
- Pending further analysis, there is an apparent need for higher spatial resolution of <1 m.
- Timelines requirements tend to cluster. The government sector has more interest in real time than other sectors do. Nearly 60% of commercial-sector interest clusters from 1 to 3 days and 1 to 3 months.
- Aerial imagery is used 65% of the time. Multispectral imagery is the most used type of imagery collected by space platforms. Digital is the most used imagery format.
- For imagery, the largest increases in usage in 2006 are projected to be hyperspectral, light detection and ranging (LIDAR), digital color, digital black and white, and color infrared film.

## Conclusions

- The commercial RSI market is growing at about 13% a year, although the impact of September 11, 2001, on this estimate is unknown.
  - Market size was about $2 billion in 2001 and will grow to $6 billion in 2010, in constant 2000 U.S. dollars.
  - Aerial and satellite markets do not seem to be competitors.
- The industry is fragmented and populated with many small companies. This does not necessarily mean low entry barriers.
- Imagery collected from aerial platforms is used twice as frequently as imagery collected from space platforms.
- High resolution, geolocation, and cost are market drivers. However, information value and content have a strong influence and can supersede cost issues.
- Digital is the preferred format.
- Companies typically operate in more than one business segment.
- Government agencies are the largest potential customer group. About two-thirds of commercial RSI revenues through 2006 are from the federal and state governments.
- In all sectors, the barriers to growth appear to be funding, education, training, and awareness—not available technology.
- Currently, across all sectors, the most active applications or market segments are as follows:
  - National and global security—41%,
  - Mapping and geography—17%,
  - Civil government—15%,
  - Transportation—9%,
  - Environment—4%,
  - Utilities—4%, and
  - Other individual market segments—2% or less.

## Note

1. The preceding was a summary of Mr. Plasker's presentation. Copies of the slides in the presentation, which include details of the forecast's findings, are available at http://www.asprs.org/asprs/news/forecast_frame.html.

Session 7

# State of Remote Sensing in Transportation

## Summary Panel

David Fletcher, *GEODIGM, Moderator*
Ian MacGillivray, *Iowa Department of Transportation*
Anita Pauline Vandervalk, *Florida Department of Transportation*
John J. Conrad, *Washington State Department of Transportation*
Walter H. Kraft, *PB Farradyne Inc.*
Michael R. Thomas, *National Aeronautics and Space Administration Earth Science Applications Directorate, Stennis Space Center*
James R. Plasker, *American Society for Photogrammetry and Remote Sensing*
John R. Jensen, *University of South Carolina*

*David Fletcher*

This is the conference feedback panel. Evaluation questionnaires from last year indicated this type of wrap-up session was one of the most valuable aspects of the conference. This year's panelists have spent a lot of time thinking about the bigger picture, and they will offer some synthesis remarks and observations and provide a perspective that rounds out a lot of the technical material that we heard yesterday.

We asked the panel to focus on key questions. Since the program is now 2 years old, we are trying to think of this as a midterm assessment or evaluation. At the first conference last year, we were still exploring each other's vocabulary, needs, and interests in the remote sensing community and the transportation community. We have seen some good progress over the last year at the application level.

The first question is what are the greatest strengths offered by remote sensing technologies to transportation and program activities? Is there something uniquely different about remote sensing, and are there activities that can play to that strength?

Conversely, it is equally important to identify the current weaknesses of the technology. What are we doing, or what is the industry doing, to go ahead and address those weaknesses?

These are two questions internal to the industry, gazing inside from the perspective of remote sensing. As we begin to look out, what are the external factors that influence the success of the program? The first external factor is, obviously, what are the best viable opportunities that are being explored? Viable is different from do-able. We have seen a lot of research that remote sensing is technically feasible, but that does not necessarily make it viable or sustainable or desirable in an operational setting. We want to begin to think, given all the projects, are there any that begin to stand out as real core activities? We should then think about strategies for deployment within the industry—deployment and commercialization.

Along with that is the question: Are there new transportation policies and program areas that are just now coming on line that could benefit from the new technologies? We spend a lot of time matching new technology to old missions. In some cases that is probably a good fit. In other cases, rather than spending all our energies looking at how new capabilities could be applied to old operations, we can also ask, Are there new operational responsibilities that we can match against the new technologies?

Finally, are there any kinds of external threats? Are there factors that would tend to threaten or change the slope of the deployment curve shown in Jim Plasker's presentation? [See session on a 10-year remote sensing industry forecast, page 47.] Now we are looking at an 8% growth rate for remote sensing. What are the threats that could change the slope of that curve?

I'll start, since that is the moderator's prerogative. My view is that in a much broader sense than we have thought about it, remote sensing has inherent strengths that are worth exploring. Remote sensing technologies, by their definition, are nonintrusive. They offer an over-the-horizon access to places that are either prohibitively expensive to reach or are impossible to have access to by any other means.

The other trend we are seeing is for multispectral sensing, the hyperspectral with hundreds of channels, and ultimately to ultraspectral sensors with thousands of channels, and perhaps the thousands of channels will be user-programmable so an analyst can select a particular part of the spectra to analyze.

Another significant strength: these data are, on a per sample basis, essentially free. In a 1-$km^2$ area, at 1-m resolution, there are a million data points. Even if it costs \$40 or \$50 to buy a million samples of data, that is less than a penny a sample. That completely changes the relationship I have with the feature or the phenomenon that I am beginning to view. I can begin to think about continuous types of monitoring activities.

We've seen a lot of small-area applications, and I think the pilot level is a good way to start. But I would encourage us to play to the strengths of the technology, to consider, How can I take advantage of data that are less than a penny per sample? How can I take advantage of data where I now have hundreds, if not thousands, of items of spectral information with the high-resolution information?

On the weakness side: a number of folks stood up and said, "We had a data collection mission scheduled that we had to scrub because of poor conditions." The paradox is the greatest weakness for remote sensing: the greatest need for remote sensing information is generally when the data are the least available. We want data during storm events. It is very hard to launch a tiny plane during the hurricane. What happens in nighttime events? What happens in fire events when smoke produces visibility problems? The timeliness of the information is affected by the revisit cycle of the sensor: the sensor came over this morning, the event happened in the afternoon, it is 4 days before I get that sensor back again. How do we deal with this? Certainly, transportation people are unwilling to put mission-critical safety issues onto unreliable technology. If that technology is inaccessible, I consider it unreliable, and it is not worth the investment just for sunny days. I need a technology that operates 24/7.

The other weakness, mentioned by many speakers yesterday, deals with the data-to-information transformation process. Human beings are incredibly good at all the things that software is not good at. We've got a million years of evolution at basically a preconscious level that have taught us pattern detection, trend line recognition, and anomaly detection. Of course, those are all the things that we want from remote sensing products, and they are the most difficult things to write in the software. Until we take human intelligence out of the loop and replace that with machine intelligence, we will have this barrier. There is an enormous shortage in the qualified workforce. It is unlikely, at least in the short term, that there will be a huge infusion of new industry professionals. We will have to start talking about coding intelligence rather than hiring it.

In terms of opportunities, it is the same. The transportation industry has advantages that some other industry segments do not. We can take a much more systemic approach. Most remote sensing projects are based on the assumption that we have smart sensors and dumb features. We don't have to live that way. We can create the digital world, because we are creating engineered facilities and can have smart sensors working on smart features. For example, in trying to identify where pavement is, rather than doing feature extraction and assuming that the pavement is passively sitting out there, if I have a cheap mixture, say a \$1.00/lb add mixture, I can throw that into a pavement mix. If that add mixture has a specially designed signature, then the signature will show up quite clearly. It makes the feature extraction that much easier. Likewise, if I have the library of spectral response from car colors, which is only several hundred paint shades, identifying those vehicles out of the backgrounds is much easier.

Let's take a systems approach then: design smarter features that can take advantage of the remote sensors, so that the two begin to work together. I think the best example is intelligent transport systems (ITS). I would assert that, given all the ITS experiments in applications and the demonstration projects, there has been only one clear-cut example of success in the entire ITS industry and that is electronic toll collection. We have done many things, but the only thing that has been deployed nationally and that all 50 states are using is the EZ-Pass toll system. It is a good illustration. Originally, toll taking was a human-to-human interaction. I searched around the glove compartment, found 40 cents, and I handed the 40 cents to the toll taker. Now, it is a vehicle-to-infrastructure interaction, which takes the human being right out of the loop. Now I have a smarter car and a smarter road, and I don't need the people to conduct the same transaction. At the same time, the public benefits improved: travel times got better, environmental air quality improved, and it was tied to a program that had a revenue stream. Those are the kinds of opportunities and the kinds of systems engineering that would be useful for us to investigate.

Another opportunity is condition surveys. We need to think differently about the way we do condition surveys and design the structures themselves. We need to design phenomenon in the structures to take advantage of the unique characteristics of the sensors, rather than trying to retrofit the sensors back to the condition survey. The project on the bridge condition survey is an example.

Threat. There is, and will continue to be, the tension between openness on the one hand and restriction of information on the other hand. Where we set that balance point will determine the impedance of the deployment of these technologies in the industry. What to one person looks like improved customer service, to another person looks like invasion of privacy. What to an agency looks like regulatory monitoring, to an industry looks like the capability for industrial espionage. What looks to government like infrastructure management, from another perspective looks like infrastructure vulnerability. Negotiating the balance between transparency and the restriction of information will probably do more than the inherent technical capabilities in determining the diffusion rate of remote sensing.

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## *Ian MacGillivray*

I cannot focus on all five of the panel's charges, but I would like to address three of them: opportunities, barriers, and threats.

I see the opportunities in the environmental area. The most immediate barriers are organizational within the departments of transportation (DOTs). I want to talk about myself and my organization for a couple minutes and how that relates. On the question of showstoppers: some of the new tools and the results are showstoppers that can potentially revolutionize how we do some of our work.

Administrator [Ellen] Engleman [of the Research and Special Programs Administration of USDOT; see the opening session on page 10] graphically pointed out the gap in going from research to commercialization. We now face that gap, she said, in achieving commercialization, although I prefer to use a different word. I call it implementation. I want to focus on those questions. In effect, it is a start on strategic planning. I'll come back to the gap a couple times.

There are two themes through much of the discussion and presentations at this conference. One is that remote sensing technology is "not quite ready for prime time." The other is that "the prime customer," and I guess that is the DOTs, "is a resistant customer." This morning the industry survey [see session on a 10-year forecast for the remote sensing industry, page 47] showed two considerations that I think are key: speed and the availability of information in our development process. You're darned right. That is one of the most perceptive things you can say about the transportation business, particularly when it comes to location planning, environmental analysis, and developing projects. Cutting down that lead time from 5, 6, or 7 years on project development will get us back in the realm of reality with lead times of 2 and 3 years.

The survey found that information is valued by the customer. That is real logical. Lower cost is not critical but that would close the sale. I'm not concerned that we have an emphasis just on cost. The most important point that was made from that survey is the insufficient level of customer knowledge of remote sensing. It is hard to buy what you don't know. It is hard to use it. The demonstrations, as we have seen from our university consortia partners, are key in that.

The transportation sector looked a little smaller in the survey as a customer than I would have expected. Just as we, as customers, lack some adequate knowledge about remote sensing, perhaps the remote sensing community also lacks some adequate knowledge about us as customers. The industry needs to have a better idea of and the research community needs to better understand the customer, to look at our prime needs, so that we don't get another way to do what we already do, only with a new tool. There is no real strategic advantage to that. Yes, maybe it is more cost-effective, but we also need to understand how the prime transportation customer, the DOT, does business in the environment in which it works and how the presentation of information from these tools could be more usable.

### Barriers to Entry

Accuracy, vertical accuracy, is critical. Can you imagine what a 3-m or 10-ft vertical accuracy means to a designer or a location planner? It means the data are virtually useless. Think about a 10-ft cut in rock fill or a 10-ft cut for a back slope and its impact on the footprint of that right-of-way and what that footprint means in an environmental assessment for alternative highway locations. We can't work with it. In some ways, the vertical accuracy of remote sensing is not quite there yet, although digital terrain models with 0.5-meter accuracy are a breakthrough and are going to allow us to do many applications.

### Better, Quicker, Cheaper

I'd like to turn this phrase around and suggest that the challenge is quicker, better, and cheaper—quicker, quicker. One of the best opportunities for adoption is in the environmental area, but I want to put that in a broader context. This is location planning and design. From the technical side of the traditional engineering, like cuts and fills, all the way through to areawide coverage, there are various environmental factors. The ability to look in the early stages of the alternatives analysis at environmental influences and analyze not just a preferred alternative, but a variety of alternatives, and to do that cooperatively with resource agencies and with the public is very desirable. To do that means that the information from remote sensing needs to be understandable, and it needs to be presentable in a fashion that relates to the decisions that are going to be made.

We're participating in a wetland project right now. I'm very enthusiastic about what it is going to do for us. As I present the information to the public, it is clear that there is more to a wetland than just calling it a wetland. Some issues are quite significant, and some aren't significant at all. As a user of the information, I have to have a way to convey the difference in that significance as we talk about measuring the impacts of our work. We have to present the information in a way that folks can appreciate it, and yet there are going to be people that don't have the background that we're presuming as we talk even to that educated customer.

I'm excited about everything, from digital terrain models to environmental representation of information that is now becoming available. I'm excited about the tools that let us evaluate and optimize those locations from that information. Let us optimize the analysis of our locations through value sets. Value sets can be dollars or environmental measurements of various types (wetlands, prime farmlands), but they are primarily the values of the communities that we work with and the methods that let us rapidly turn that information around for them. Such tools are also becoming widely available and need to be integrated with this practice.

There are two gaps to focus on: the knowledge gap and the use gap. The knowledge gap is perhaps more important. Several times the resistant customer was mentioned, or it was said that the DOTs are not early adopters and are somewhat risk avoiders. You probably need to understand us a little bit better. Those are superficial characteristics, but they are valid observations. Why? One of the reasons is that a lot of us are civil engineers; we are a can-do organization. We were crafted with that, and we take pride in that. What do I mean by "can-do"? We can do it ourselves. We are talking about changing the environment of practice in most state DOTs, because state DOTs are probably not going to do remote sensing. We are not going to collect this information. This is a foreign intrusion into our process, and that is a part of what we are somewhat resistant to, and it is very difficult to get us to understand and adopt.

That means, then, developing innovative partnerships and working with DOTs in demonstrations to apply and learn from these technologies. In fact, that is what we've been able to develop with our university, and we are very proud of that successful partnership that is working very well with Iowa State University. That is a plug for you, and good job.

## Innovative Contracting

DOTs are a little resistant to innovative contracting, too. The remote sensing community needs to be thinking about how to present us with opportunities to partner with you in more innovative fashions that allow you to combine the things you can do with us with the things you can do with other people that we may not understand as well.

The demonstration of the tools is perhaps the best opportunity. I'm concerned about some other gaps: the gap between pure science that produces entertaining results and the application of useful information that relates to the decisions that we need to make. I'm also concerned about doing some true measurements—not environmental measurements, but measurements of the impact on the process itself. Are we, through the use and application of remote sensing technologies, having a positive impact on the process we are responsible for? One way that is measured is by how long it takes us to develop our projects. Another way is by measuring the quality of the projects that we develop, in essence, in total in the environment and in the community and also with the users, but particularly in the environment and in the community. We need to look at how to contribute to improving that product with these methods.

The one thing I would like to leave you with is that perhaps when you look at me, you're looking at one of those uneducated users who need to better understand what the potential is. The challenge and the invitation to you are to educate me on how I can help my agency best take advantage of what you have to offer. You need to understand my terms of business and the decisions that I face, and we need to begin exploring ways to get beyond the research community. Today, people like Dave Ekern [of the Minnesota DOT], John Conrad [of the Washington State DOT], and I are here representing our organizations more from a research viewpoint than from a development and practicing engineering viewpoint. We now need to start approaching an integration between this science that is coming out of the cocoon and sitting down with those civil engineers, those old-fashioned fellows and ladies, and talking about how to modernize some of their practices.

I encourage you to make your next engagement to be not talking to each other or to us, but perhaps visiting with the committees at the American Association of State Highway and Transportation Officials (AASHTO) and perhaps Tom Palmerlee [of the Transportation Research Board (TRB)] and others who can assist us in that integration.

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## *Anita Pauline Vandervalk*

I'm Anita Vandervalk, the Manager of the Transportation Statistics Office at the Florida Department of Transportation. I'm a planner, an engineer, and a data manager, so I'm going to talk from those perspectives. I will concentrate on the flows in infrastructure areas, as those are what I'm most familiar with and to which I have something to add.

I'm going to organize my comments into three areas. I will talk about strengths and weaknesses and then focus on opportunities. Many of my comments are a continuation of Mark Hallenbeck's comments from yesterday [see the session on transportation planning, page 28].

As we have heard over the last couple of days, there have been a lot of improvement and a lot of progress over the last year in the flow area, but beyond the technical advancements, even more important are the improved relationships and the communication and coordination that have occurred. Last year we heard a lot of "we" and "them," and we are not hearing that this year. There is a lot more discussion about how all of this can benefit all of us in the transportation community.

On flows, I think there is the potential to provide low-cost continuous data. This is a strength, but it is also a potential weakness because we do not have the ability to provide that "any time, anywhere" data. As Mark Hallenbeck indicated, there is a lot of potential, but still quite a way to go before the data can truly replace the way we measure volume and report on level of service and speed calculations.

What we need is to decrease the cost per unit of information that we are getting. The technology needs to work accurately and consistently and be more cost-effective than the alternatives we are already using.

As far as weaknesses go, I agree that we need to continue to work on improved vehicle detection, tracking, and automation so we can turn the data into information. We need a system that is simple enough so that existing employees can use it. We have heard a lot about that already. Very importantly, despite the difficulties in being able to provide benefit–cost ratios, we need to at least look at cost comparisons between the spatial technologies and get some indication of what the "added value" is for our transportation processes. That is something we need to do together. That we, in the transportation community, expect the remote sensing community to come up with that has, I think, been part of the problem, when this needs to be a joint effort.

We also need to be careful with an approach that simply replaces existing data collection techniques. We can't take a data collection methodology and assume that we can replace it with a new spatial technology. We should aim to use the spatial technology and spatial information tools as tools to improve our transportation business processes. Again, that is something we need to work on together.

An example that I want to use is yesterday's presentation on level of service [see the session on transportation planning, page 21]. The techniques presented were good and applicable. We, at the Florida Department of Transportation, did take some aerial photography and try to measure density, and we used that measurement in some of our performance measures evaluation. I'm going to talk a bit from the standpoint of performance measures, because we are working very hard on developing mobility performance measures, and the need to come up with data collection techniques is high on my list.

We looked at that technology to report on level of service, and it did not mean a whole lot to us. The reason is that as an agency, we are turning to look more at operations. Operations is important, and our customers are expecting reliable transportation. We are searching for reliability measures, measures of travel speed, and the variability of those speeds along a corridor. For the measurement of level of service, although that possibly meets an existing or an old demand, we need to be looking at other ways of measuring different metrics. For example, it would be great if we could get something that would give us good travel speeds consistently and regularly, since the traditional travel time runs are relatively expensive. We must be careful not to assume that we are going to continue to measure things the way that we do now or that the accuracy levels have to be what they are. We shouldn't fit remote sensing into transportation, but rather again, improve our overall processes and figure out how remote sensing can help us do that.

Another example: in Florida I'm working on improving our data collection process from the planning standpoint. We are looking at using remote sensing or aerial photography to collect data at the early stages where we collect our roadway characteristics inventory and our Highway Performance Monitoring System data. We are trying to figure out at what accuracy level we can collect so that data can better serve the environmental folks in precorridor studies and possibly even predesign.

One of the interesting things we found is that the designers do not know what accuracy level they need. They are assuming that their providers, being the surveyors, are providing it at the Level 1, Level 2, Level 3 survey, or at whatever level they are getting. We need to get at the question of what accuracy do they need and couple that with what accuracy can be provided by remote sensing technologies.

If the new spatial technology can work with us in a way that will help us revamp our processes, and help us figure out a better way to do business, then we need to think more of the bigger picture. All of this will challenge us to work even more closely together as we endeavor to do that.

On the opportunities, I think I have already alluded to some of them during my discussion of weaknesses, but some measures Mark [Hallenbeck] wanted me to mention that we could use would be measures that give us queue detection, park and ride utilization, flow, origin and destination, vehicle class and size, and emissions. He felt fairly strongly that there must be a way to figure out a new way to measure the total air pollutant load by facility or area, which will get us away from trying to figure out emissions based on vehicles.

It would also be great if the sensors could help us see both a wide focus area and a narrow area. Then we can use the wide area to figure out where there may be a potential congestion or transportation problem, and then narrow in on the problem and go ahead and collect data at regular intervals to help us figure out how to operate the system more efficiently.

Another opportunity lies in the collection of multimodal and intermodal data. I've seen some potential projects in that area. Another example from Florida, which is illustrative of other states as well, is the development of a strategic intermodal system to move beyond the traditional approach of prioritizing projects on an interstate system. We are in the middle of developing an intermodal system that will include ports, airports, transit, and highway, and figuring out how to prioritize projects among and between all of those modes on a systemwide basis. We are definitely going to need some way to measure flows of people, commodities, and goods as they move through the system. That would be a definite opportunity area for us.

In general, I think there is a good amount of potential in the flows area and especially in the infrastructure area. Again, we still need to work together to see the big picture and how we can get the most out of remote sensing technologies.

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## *John J. Conrad*

I'm John Conrad with the Washington State Department of Transportation. I'm going to focus on strengths, weaknesses, and some emerging policies and programs. Much of what I'm going to say will reinforce what you have heard from Ian MacGillivray [of the Iowa DOT, see the session on environmental streamlining, page 20] and Anita Vandervalk [see this session, page 55].

First of all, on the strengths side, I think remote sensing provides a richness of data that is a natural fit with the DOTs. I talked about the build, maintain, operate function that makes up most of what we do, and it fits very well with that.

I think there are great opportunities for doing things faster, better, and cheaper. The ones that most piqued our interest are in the environmental and hazard assessment areas. They, in particular, lend themselves to this technology. We're demonstrating that by our involvement with the I-405 project [see the session on environmental streamlining, page 19] that we described yesterday.

Infrastructure, I think, also has the potential to offer some significant benefits, but what I see as an emerging strength is more emphasis on user involvement. It is good to see a number of DOT folks and others here that are actual users of this technology, and it is good to see that many projects being researched right now have strong involvement from agencies that are the potential users.

Now I want to talk about some of the weaknesses. One problem is that remote sensing is a very technical subject that is not easily understood by those of us who aren't working with it day to day. There is a natural skepticism because of that. The challenge is, How do you overcome that skepticism and get the right information on the benefits, costs, and how this fits in with our mission, to those of us who are decision makers in our agencies?

If we reflect back on the history of research in DOTs, the biggest research project that we ever had was the Strategic Highway Research Program (SHRP) in the late 1980s. Hundreds of millions of dollars were expended on research as a part of that program. The big weakness that was uncovered as that program wound up was that not much thought had been given to implementation of the research. That is a key lesson that needs to be kept in mind with remote sensing.

What ultimately came about with SHRP was that implementation groups were formed, both within TRB and within the AASHTO organization. This went a long way toward getting that research into actual practice. That mission could have been a lot easier had thought been given to this problem up front as the research was being put together.

I particularly liked [session Moderator] Dave Fletcher's comment about designing systems that take advantage of the technology (see page 51). The only way that will happen is through a strong connection with those user groups, such as AASHTO. I want to talk a bit about how AASHTO works as an organization and how the remote sensing community might fit in with that and TRB as well.

Let me start with TRB. As [TRB Executive Director] Bob Skinner mentioned Tuesday [see the opening session, page 10], the TRB and those of us in the business put a lot of hurdles out there in front of research. We are not trying to put barriers out there to implementation, but that is certainly how it comes across. TRB last year formed a special task force on accelerating innovation in the highway industry—a group of industry and DOT officials from across the country that are trying to identify innovations and address how they might be mainstreamed and accelerated into practice. That is one model for this.

AASHTO is essentially formed of all the DOTs from across the country. One of the primary committees within AASHTO is the Standing Committee on Highways. That committee is the most technical committee of any of the AASHTO committees. That is where all the design, construction and traffic operations, maintenance, highway safety, etc., are discussed through subcommittees for each of those technical areas. That Standing Committee on Highways is made up of the chief engineers from all the DOTs across the country. The subcommittees are made up of actual practitioners from each state DOT. Learning from the SHRP experience: as AASHTO phased out its SHRP Implementation Task Force, it continued with the new group called the Technology Implementation Group (TIG). This new group is trying to find technologies that are ripe for mainstreaming and implementation in the DOTs and lending a hand to making it happen.

One of the most successful approaches developed for technology implementation is the lead state program. This technique relies on identifying those states that are out front in leading and implementing the particular research or technology, and then using those states as a user and teacher model with other states that may be interested in implementing the technology. The TIG and SHRP Implementation Task Force have both made good use of this approach within AASHTO.

On emerging policies and programs, I think Anita Vandervalk has hit it right on the head with flow and operations. The highway system is fairly mature. It is built out, and focus needs to be on how we operate that system. Making the system operate as efficiently as it can is now being recognized by virtually all DOTs as extremely important. It is coming together in a national focus that I think will lead to incorporating some language on operations into the reauthorization of the Federal Aid Highway Program next year.

A key part of operations is knowing what is going on in your system. Now our basic way of knowing what is going on relies on very extensive hardware, such as sensors in the pavement or closed-circuit TV cameras, which are very expensive and are not easily implemented. We are searching for less expensive ways to detect incidents, measure traffic flows, and know what is going on out there in the system. We are looking for ways to speed up our response to accidents and incidents on the system and get them cleared more quickly.

Lastly, we are challenged to measure the performance of our system, and Anita Vandervalk has given you ideas of those measures that we need to keep track of in operating our system.

I want to thank everybody for the opportunity to participate in this workshop. It has been a tremendous learning opportunity for me.

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## *Walter H. Kraft*

Good morning. I'm Walter Kraft. I'm a civil engineer who migrated into traffic engineering and ITS. I have to admit that when I was here last year, I was a bit lost in trying to understand remote sensing technology. It was very detailed, and even though I consider myself a technology buff, it was over my head. This year, I feel more comfortable, because I think the gap in my understanding of the remote sensing technology has been reduced.

I am reminded of the evolution of the mobile telephone. Remember those breadboxes we used to carry around as mobile telephones? I had one and kept it for many years. Over time, the phones got smaller and became more usable. However, when I went overseas, I could not use my mobile telephone because of different standards. I remember my colleagues in Hong Kong, who would change the chip in the back of their telephone to use that same device in Beijing. Now there are mobile phones that are interoperable in different countries, and you don't have to change the chip. I sense a similar evolution in remote sensing.

I would like to share some thoughts with you. I did not do a rigorous breakdown of my summary by the suggested categories. However, I will cover strengths, weaknesses, opportunities, and threats. I want to share some capabilities that are needed in operations and that I think are important, and maybe some can be solved with the use of remote sensing. Our challenge is to separate those needed capabilities that can be provided with remote sensing and those that should be provided through other sources.

Operations need real-time data. Real-time data can have different meanings. It can mean second-by-second monitoring. In other cases, information in 5-min intervals may be sufficient. For operations, I need frequent data, and I need it continuously.

We need to improve safety. Each year, we kill more than 40,000 people on our roadway system. That is an epidemic. As I mentioned yesterday, 31% of police fatalities were attributed to highway crashes [see session on lifelines and hazards, page 45]. The roadway is a hostile and dangerous environment.

Let's take a look at an incident, which can be primary or secondary. It can also be planned or unplanned. An example of a planned incident is roadway construction or a major event. An unplanned incident is a crash, or wreck or accident, depending upon which part of the country you are in. Let's assume that two vehicles crash, causing a primary incident. The effect of the crash is that the traffic upstream of the primary incident slows, stops, and backs up. Primary incidents provide opportunities for secondary incidents to occur. In many cases, the secondary incidents are more severe than the primary incident, because a high-speed vehicle hits a stopped vehicle. The objective of incident management is to clear the primary incident before secondary incidents occur. To help understand the situation better, let me explain the incident management process.

Incident management has three parts: detection, verification, and response. First, we need to detect an incident. Then we need to verify that the incident has occurred. Lastly, we need to respond to the incident. Response is directing those resources that can clear the incident quickly and effectively.

I've been in some states where it takes the police 33 min to verify an incident. That is too long just to verify an incident. Such a long verification time provides too many opportunities for secondary incidents.

What we need is information; we need to know quickly when an incident occurs. Currently, about 5% of the nation's roadways are instrumented, either by intrusive devices where we put detectors in the roadway or by nonintrusive devices that can be maintained without causing congestion. These devices are expensive to install and maintain. We can't afford to provide the same level of detection on all of our nation's roadway system. We need to look for alternative ways of detecting incidents.

In urban areas, cell phone users provide us with timely, but not always accurate, incident information. We don't have that same opportunity in rural areas. Many rural areas don't have very good cell phone coverage.

We also need to know information about the roadway system when an incident occurs. How many lanes are blocked? What types of vehicles are involved? Do we need the big wrecker or will the small wrecker be sufficient? How do we handle the incident? Are there injuries? Do we need to get medical personnel there? Is there a fire? Does the fire department have to come out? Is there a fuel spill on the road? Is there hazardous material in the vehicles involved? We need to know the answers to these questions as quickly as possible.

I would also like to know what happens if we have an incident and traffic diverts. Diversions can be planned or unplanned. Planned diversions provide drivers with information on suggested diversion routes. The objectives of planned diversions are to help drivers get through the roadway system more effectively, keep them out of neighborhoods, and keep them away from schools. Unplanned diversions provide no information to drivers other than that there is an incident ahead. Drivers then travel on diversion routes based on their own knowledge and without information about the diversion routes. Real-time monitoring by remote sensing could reduce the effects of diversions.

I also want to know what parts of the road system are not usable due to natural or man-made disasters. Reactions to hurricanes consist of evacuation, sheltering, and recovery. I need to know when to stop evacuation and start sheltering. Likewise, I would like to know when the recovery process could begin. For example, there is a section of Route I-10 east of New Orleans that frequently floods during hurricanes. I would like to know when vehicles should stop using that section of road so that vehicles don't get stuck in a queue at the flooded areas. I would also like to know when the road could be passable again.

Another application of remote sensing is to provide information on the location of fog. Currently, we can obtain information from point source weather stations and interpret the area of fog. I would like actual information on the areas covered by fog.

Yesterday, I asked if we are measuring the right things. For example, the Minnesota legislature decided that the ramp-metering system in Minnesota should be discontinued because of public concerns. The engineers were focusing on maintaining free flow on the freeways, while the public focused on the ramp backups. Fortunately, when the ramp-metering system was shut down for a few weeks, travel was negatively impacted. The net effect has been increased awareness of the effects of ramp metering by both the engineers and the public.

I would like to give you some challenges to address. How can you provide real-time data for operations? Also, are we measuring the right things? Is remote sensing the right technology for what we need to measure? If it is not the right technology at the present time, will this conclusion change over time as the technology evolves? For example, a few years ago, unmanned aircraft were not considered as viable options to gather real-time information; now they have become a viable option.

We need to get the message out that remote sensing is a viable technology for operations. TRB has a number of committees that each of us could inform at their meetings. I am a member of the TRB Committee on Freeway Operations, and I will inform them of remote sensing. I hope that you will also spread the word.

We need to continue to move beyond planning. Last year, the meeting's focus was on planning. This year there were many applications dealing with operations, such as lifeline disruptions, evacuation planning, airports, and flows. The gap has been reduced from last year.

Let me summarize the strengths, weaknesses, opportunities, and threats. A strength has been reduction in the gap between technology and applications presented at this meeting. Some of the weaknesses are that we may not be measuring the right things or applying technology the right way. The opportunities are there. Let's go beyond planning and address operations. The threats are the nay-sayers that say we can't do that. We need to think outside of the box and continue to make great strides similar to those we made since last year. I am looking forward to the great strides that we will make before next year's meeting.

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## *Michael R. Thomas*

I'm Mike Thomas from NASA. I would like to make a couple of observations. One is I am a NASA person, and NASA is interested in the Earth as a planet. Typically we look at really big things. We look at planet-size things like the global climate change, which NASA is interested in, and the circulation patterns of oceans.

When we look at the land, generally we are looking at how large-scale human activities are going to affect climate or weather. Are we causing it to rain more in one place and not in another, or are we causing the weather to warm up?—questions like that.

Therefore, the conventional wisdom was that NASA was interested in very-low-resolution images of the Earth, a scale that would not be applicable to an agency like a DOT that wants typically very-high-resolution images. A couple of years ago Congress set aside $50 million for NASA to buy commercial data. This was done primarily at the urging of commercial data providers for using commercial data from remote sensing for the earth science community. What happened? People beat a path to our door. We couldn't get enough information, and we couldn't get it out to the earth scientists quickly enough. They found from the data that anomalies that cannot be explained with kilometer-size data can be explained if you can see into the kilometer-sized data and figure out what exactly is going on in that higher-resolution data. Now, IKONUS 1-m size data are being used by the earth science community a lot. The models that we use to calibrate and program at the 1-km level, we are finding, perform much more accurately with higher-resolution data. Now we are running up against the model's ability to take in these data at these scales and perform, because the computation complexity goes up so much when the resolution of the data is so much higher—but then the product is so much better.

From NASA's point of view, it looks like we will probably, and this is a prediction, continue to be interested in higher- and higher-resolution earth remote sensing data. I believe that with the advent of Quick Bird II, the new satellite that has just been launched with 6-m resolution, NASA scientists will take all they can get.

It remains true that NASA is interested in things that the general public probably is never going to be interested in, like atmospheric chemistry, for which there is a very small customer community. I believe NASA will continue to build satellites, collect that kind of data, and make them available to the science community, but the land observations are probably going over into the public domain. Probably NASA is going to buy data over land areas from commercial providers, rather than put up its own satellites as it did in the past.

Now, because of these changes, we are doing something at the Stennis Space Center that we would not have done a number of years ago. We are very interested in understanding the sensors that are providing this land data. We are building a calibration range at the Stennis Space Center for commercial instruments. One need we perceive in the growing remote sensing industry is for some way of characterizing instruments so that the data they produce are comparable. Different vendors sell different kinds of instruments. Light detection and ranging (LIDAR) is a good example. The performance of those instruments is, by no means, the same. Depending on how the company providing the LIDAR uses it and how it processes the data, the results could be quite different from the results you would get if you hired another company. The U.S. Geological Survey (USGS) for years has performed certification of aerial cameras. USGS and NASA are entering into an arrangement whereby NASA will help USGS in understanding new instruments as they come on line and the characterization of those instruments, and USGS can continue in its role as a certifier of those instruments. I think this will be valuable to the industry. We are very excited about it at Stennis. Working with USGS, we are starting a LIDAR calibration range and a digital camera calibration range. As new instruments become popular and as the commercial demand for data from those instruments grows, we will probably upgrade our facilities to be able to characterize those instruments.

This leads me to another future area. I believe NASA, as an agency, is probably going to become much more interested in active sensing. Right now, the camera systems, even in the visible range and also hyperspectral and multispectral, all use illumination from the sun. The sun is a great source of illumination, but we only have it for certain hours of the day. Also, it does not illuminate things very well under clouds, and when we are flying we don't see well through the clouds. We are becoming more interested in how we can design sensors that provide their own source of light, a source of energy, because we can control that source. We can understand it. With a LIDAR, when we send a pulse out, we know what the beam composition is, so we know how to interpret the response much better than we do when we just use sunlight.

We are very interested in what new kinds of sensor designs and new kinds of processing can be done with LIDAR, with synthetic aperture radar, and others. I predict NASA will make more of an investment in understanding that end of the technology as time goes on. As we get results there, we want to work together with the user community, the DOTs, and others, to understand what those new sensors can do for that operational community. I go back to the previous speaker's saying, "Let's understand the question before we apply a sensor to a particular problem. Let's understand what we are trying to figure out here and make sure we have the right sensor for the right job."

In comparing this year with last year, I also have noticed a big difference. The projects this year are very applications-oriented. They are very understandable by the applications community. I agree that it is time to take the next step, which is to get the operational community much more involved now. We are ready for prime time in some areas, and we need to remind ourselves that people don't buy technology—people buy products. What do we have to do now to make a product routinely, operationally available? It is not enough to show that something works. Somebody has to buy it. It reminds me of the early days in the Defense Department when I was flogging new high-tech products. The worst thing that would happen was that after giving a demonstration, some general would stand up and say, "I want 10 of those, so where do I go to get them?" You would have to say, "Well, General, there is only one and it takes eight Ph.Ds." That was it. Everybody left the room, and you were done. I don't think we want to create the expectation that all of these technologies are ready for adoption instantly unless, in fact, they are, unless we have somebody in the back of the room who is writing orders. We should be careful about saying this is ready for you to buy, you can have one in Iowa, and you can use it tomorrow. I guess that is my only caution.

## *James R. Plasker*

I thought I would go down the list of questions with just a few bullets on each one. I wasn't here last year, and therefore I don't have the benefit of the comparison from year to year. I'm also somewhat sensitive to the conservative nature of the transportation industry. As Yogi Bear says, "When you come to a fork in the road, take the fork." I took my fork. The fork was, after a bachelor's degree in civil engineering, to go to a highway department and do a good job there, or to go on to school and end up in surveying and mapping. I came very close to be sitting in the other chair, so I think I understand a little bit of that conservative nature.

On the strengths of the technology, you can make a long list. I have a limited subset, and since I am sixth or seventh on the panel, a number of these points have already been made. Some could argue whether they are strengths now or strengths eventually to be realized. Clearly, some remote sensing technologies facilitate or could, if we used them properly, real-time acquisition. You can't do that from a satellite, but that doesn't mean you couldn't do it from an uninhabited aerial vehicle (UAV). It doesn't mean you couldn't do it from a pole-mounted video camera, and an analog return might have made it more complicated in the past, but all that is digital now. Taking time-sequenced images from a pole and using them in an analysis situation certainly would facilitate real-time acquisition.

The point was made earlier that the incremental data cost is near zero, and I think that is a real advantage of most of this technology, but in real time. Once the pole is up with the camera and the processes are in place to use it, the data themselves are nearly free. The processing of the data may not be, depending on how many humans need to be involved in that process, but the data are very cheap.

Another tremendous advantage of remote sensing data is that you have the ability, if you need it and can take advantage of it, to have a synoptic view or synoptic acquisition. You can look at a large area and get a snapshot nearly instantaneously or certainly over a short period of time and a lot quicker than you could if you ran around in a vehicle all over a state trying to collect the same kind of information on the ground. You may not need the synoptic view, but if you do and if that can benefit you, that is an advantage of remote sensing. You can also hone in on a particular area. In fact, you could use the synoptic view to determine what specific phenomenon you're trying to pick up.

Another area that seems to me to be a real strength is that remote sensing is nonintrusive. We know about police deaths on the highways and the accidents that occur on the highways. Survey crews and other road-monitoring personnel are also out on the highway. Safety and efficiency in the data collection itself are a factor. I don't think the numbers of deaths is anywhere as with the police, but there is a safety and efficiency issue.

A comment was made earlier about needing much better than the 3-m elevation accuracy. LIDAR gives less than half a meter. In fact, I think the mega–pilot project in North Carolina is showing us that probably better than one-quarter-meter accuracy is possible, at least in relatively open terrain. Most highway surfaces are relatively open, or at least are here and there, even if there are tree-lined roads.

Weaknesses. Currently, the ability, except for the examples I gave earlier, to do any-time, anywhere sensing is limited, but where it does exist, that is a strength. To the extent that you need information and you can't have it, that is obviously a weakness.

To extract information from data takes an effort. It takes probably human intellect, and probably human time, because most of the time you can't "can" all the human intellect and put it into the software. A cost and value issue exists, and that is currently a weakness. The smarter we can make the software, the more we can

"can" the human intellect into the process, and the less that would be a weakness. But, it is a weakness.

If you're looking at satellite-based data, there are challenges that relate to the duration on scene. A satellite comes by only for a short while, so you are only going to get information at limited times. The satellite can't loiter; that is the "Enemy of the State" problem. It also only comes by every so often, every few days or whatever. The satellite is also weather-challenged; the panchromatic and multispectral high-resolution satellites we have right now are weather-challenged. If it is cloudy, they aren't going to see it. Those are weaknesses.

Where are the technical opportunities? That is an intriguing one. I alluded earlier to my experience in the digital orthophoto arena. We looked at trends. If you look at trends or look where people are likely to go next and if there is any potential for pay-off in those areas, that might be an area to concentrate on. In my mind, the war right now is demonstrating a tremendous advancement in the UAV. They are now sufficiently large and deployable that they can be used for bombing. There is talk now about having pilotless fighter aircraft—taking the human out of the cockpit totally. That means that there is a lot of investment in this. I suspect if a trend is to capitalize on dual use, the UAV is a great potential area to capitalize on dual use. We are going to see more and more opportunities to take advantage of that from a commercial standpoint. I would suggest then that if there is real value in real-time monitoring and it takes a UAV to do it, then that might be an area to watch for opportunities, because the trend is probably in the right direction.

The recent emphasis on security is pointing up the need for data integration, data fusion, and data visualization. I expect there will be a significant increase in investment in those areas driven by homeland security and by the Defense Department side of things. As that investment occurs, we might as well look for opportunities to take advantage of it.

Another trend area is LIDAR. I think we are with LIDAR about where we were with digital orthos in about 1990. We had proven technology. We had done some pilot projects. We were hamstrung by capacity of disks and media. The CD-ROM hadn't been invented yet, or if it had, it hadn't been deployed yet. Horsepower in workstations was getting there but was not there yet. It was a luxury to have digital orthorectified quarter quadrangles (DOQQs), and in fact, initially, the federal government was the only one making them. Over time, all of those trends led us to the point that today there is hardly a state government, maybe hardly a DOT or local government, that does not have DOQQs readily available. I suspect that the operating word is that when you start to plan something, you need an image base, and that is the DOQQ. We have gone, in a decade, from barely being able to do it technologically, to expecting it and having it be almost ubiquitous. My sense is that LIDAR and other terrain measurements and the visualization supported by them are in the same situation today as DOQQs then, or even slightly ahead, primarily because of what I think of as a mega–pilot project that North Carolina elected to move forward with. In looking at trends, that is a good one to follow, because I would expect the commercialization and the deployment are going to be very quick.

Another technical opportunity came up yesterday when I asked about the cell phone and the traffic flow and the centerline positioning. Several people later said essentially the same technology is being put in baggage containers and being tracked around in planes and even being put on planes to monitor plane movements. I'm not sure that is a remote sensing technology. It is not a classic remote sensing technology, but it is a technology that might bring some opportunity.

Photo radar is another opportunity. I don't know if you know the District [of Columbia] has implemented photo radar. What they did was to arrange five police cars with a photographic radar system. Instead of writing tickets, they just sit there and collect images and they can write the tickets by computer. At some point, they collected so many tickets that the estimate was that 75% of the people driving down the road were speeding. From what little I remember from 30 years ago in transportation engineering, I believe that may mean that something is wrong either with the speed limit or with the design of the road. Generally speaking though, the human population tends to obey legitimate signage in transportation systems as a group, not as individuals. Maybe there are other ways to think out of the box and, in the traffic engineering area, get the information from some other means. For example, a photo radar system today is primarily a police enforcement tool.

Policies. What policies are going to affect remote sensing? There is a mantra in real estate that says, if you want to watch real estate investments, it is location, location, and location. Those are the three factors. I think in this arena today, and maybe we're still too close to 9/11, but I think it is security, security, and security. I'll give you two examples. There is a significant emphasis now on infrastructure security, which will cause a lot of resources to be put into that in both human capital and funding. That is going to cut both ways. It is going to create a greater demand for geo-based information and for managing it, keeping track of it, and addressing it in times of crisis. There is going to be a greater demand for geo-based information. On the other hand, it is probably going to create additional restrictions on what can be shared, what can be put into the public domain, and how well that geo-based data can be made available. Infrastructure security is going to have an effect.

They are also talking now about having positive control of certain modes. The first one is having the ability to take over control of the aircraft and bring it down, in a situation that might be like what we experienced on 9/11, or of requiring certain kinds of materials to be transported with a positive control device attached. Again, that is more of a GPS technology application perhaps, but certainly keeping track of things is a geo-based function.

What are the threats? The limits on easy access to data, the public sharing of data, and the convenient sharing even amongst agencies of data are threats. I think to the extent that we let the security drive us away from sharing, that creates a threat. There may be some ways around that, but that is certainly going to threaten one of the characteristics of our society. The applications that use geo-based information, and there is a tremendous amount of it out there, pretty much freely share, with licensing being separate from that.

The other threat is, again I don't want to be critical as I could just as easily be sitting in one of those DOTs, internal within the organizations, and it is the risk-averse nature of transportation organizations. That is understandable. I would probably characterize myself that way. I would be surprised if every DOT doesn't have a group or a small group, and in some cases it might be large, of folks that are pretty savvy in geospatial technologies. Many DOTs had photogrammetric departments, although I understand over time some of that has changed. Many of them may have other kinds of capabilities as well. I lived for 26 years in a very large bureaucracy and very often the left hand didn't know what the right hand was doing. One of the questions I would have is, Is there sufficient communication going on, even within the departments themselves or within the industry itself?

For instance, the American Society for Photogrammetry and Remote Sensing has a very strong transportation surveys committee that has been meeting for years and years. It has a long list of participants, all from DOTs. There is expertise out there, and perhaps in some areas, we are not talking about early adoption, but we are talking about adopting in a different area the same technology that has served well in other areas.

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## *John R. Jensen*

I am the last speaker in the last session of the last day of the conference. Thank you for asking me to participate. I was generally impressed with the breadth of the use of remote sensing technology in transportation-related studies and the understanding of how to use it correctly. I witnessed some excellent use of more advanced hyperspectral, LIDAR, interferometric synthetic aperture radar (IFSAR), and soft-copy photogrammetric techniques. I believe that we will see a significant increase in the use of LIDAR technology for the derivation of detailed digital elevation models for the calculation of elevation, slope, and aspect. In addition, many transportation applications discussed require very high spatial resolution infrastructure information and about the only way to obtain it is by using soft-copy photogrammetric techniques applied to large-scale analog or digital imagery. We must not neglect this important area of remote sensing data collection and analysis, which is of significant value to transportation studies.

I was pleased to see that scientists in the consortia had a genuine interest in trying to determine the optimum sensor system configuration and image analysis process to apply to particular problems of information extraction. They were not trying to force one remote sensing model or data type (e.g., Landsat Thematic Mapper data) to fit all problems.

However, it is interesting to note that most of the transportation-related remote sensing projects functioned reasonably well with *un*calibrated remote sensor data, e.g., optical data were not transformed into percent reflectance, which allows multiple date comparisons to be made. In the future, more attention should be given to the atmospheric and radiometric calibration of the remote sensor data, especially if the data are to be used to monitor the biophysical characteristics of phenomena through time.

I believe we will see significant improvement in the collection and processing of digital data obtained from UAVs and terrestrial video remote sensing systems mounted on buildings and towers. I witnessed many important transportation-related problems that could be solved by the extremely efficient processing of real-time video remotely sensed data to identify vehicle location, velocity, direction, etc. This will require investment in specialized image-processing hardware and development of optimized software. Then the real-time change or velocity information should be fed into an automated decision support system that makes appropriate decisions. Remote sensor data collected from UAVs will become increasingly important. Additional effort should be directed to this important topic.

Remote sensing–derived information and other spatial information are placed in geographic information system (GIS) databases. Such information only realizes its full potential when processed using a carefully conceived *decision support system* (actually an *expert system*) that can be utilized to answer important transportation problems. The procedures developed by the consortia may eventually be judged by whether or not they perform a valuable function in a practical decision support system. It is recognized that the development of transportation-related decision support systems is still in its infancy.

Proposed transportation projects often require a wetlands inventory based on vegetation, hydrology, and soils information. Currently, jurisdictional wetlands can only be identified by ground observation. This is not surprising since most wetland remote sensing studies rely almost solely on multispectral data. They rarely utilize thermal infrared, active microwave (multiple frequency and polarization), or passive microwave techniques to assess soil moisture (a hydrologic parameter). Additional basic and applied research is required to determine what information these remote sensing systems can contribute to the eventual delineation of jurisdictional wetlands. In 5 to 10 years I believe it will be possible to perform jurisdictional wetlands mapping with specialized, multitemporal remote sensing systems. Perhaps we could arrive at this capability sooner with additional attention given to the wetlands remote sensing problem.

Transportation systems impact flora and fauna, but additional research should determine what types of indicators may be derived from remotely sensed data to predict human quality of life impacted by proposed transportation systems. People often perceive that it is undesirable to live nearby certain types of transportation systems and infrastructure. Research should begin to incorporate remotely sensed information on land use and land cover as well as demographic and cultural information to predict the potential loss of quality of living in certain areas. The more that a transportation planner can demonstrate that he or she has minimized the impact on a community's quality of life, the better.

I am very concerned about remote sensing and GIS workforce development. Who is going to conduct the remote sensing–related tasks within the DOTs? Will the remote sensing work be performed by people in the DOT, be completely outsourced, or be done by a combination of both? If the remote sensing–related studies are conducted by an in-house capability, it is not clear where the workforce will be educated or what their qualifications should be (e.g., formal academic degrees, certification, registration). If the remote sensing–related studies are outsourced, the DOTs will still need people who understand enough about remote sensing to (a) write the project specifications and (b) judge the quality and accuracy of the remote sensing–derived information.

The academic educational system cannot graduate the number of persons qualified to conduct the remote sensing–related research required by many of the transportation applications demonstrated at this conference. K-12 remote sensing education is almost completely absent.

Thank you for asking me to participate on the panel. This concludes my remarks.

APPENDIX A

# Summary of Roundtable for States and Metropolitan Planning Organizations

Prior to the 2001 Transportation Research Board Conference on Remote Sensing and Spatial Technologies for Transportation, the Steering Committee for the Conference sponsored a Roundtable for States and Metropolitan Planning Organizations (MPOs).

The roundtable was an opportunity for transportation organization staff to share experiences and strategies in the use of remote sensing. Topics included current programs and funding, new initiatives, successful strategies, and partnerships and barriers. Representatives from the state departments of transportation (DOTs) in attendance were asked to make short presentations and prepare a short paper on their current program for remote sensing and spatial technologies. Summaries of these papers are attached to this report.

David M. Gorg of Minnesota DOT, Roger Petzold of the Federal Highway Administration, and Val Noronha of the University of California, Santa Barbara, organized the session. In the organizers' introductory remarks, the following points were made:

- Interest in remote sensing is high because the number of tools available is increasing and the cost is decreasing.
- The American Association of State Highway Officials (AASHTO) has a new task force on spatial information.
- All four university consortia in the National Consortium on Remote Sensing Technology (NCRST) are preparing guidebooks for DOTs and MPOs on the use of remote sensing in aspects of transportation.
- The four university consortia funded by the Research and Special Programs Administration (RSPA) of the U.S. Department of Transportation (USDOT) are in Year 2 of the 4-year research program. The results were presented at the full conference and are available directly from the consortia.
- Representatives of three state DOTs—Minnesota, Iowa, and Wisconsin—met in August 2001 to share experiences. The exchange was very successful and identified a number of joint concerns, including vendor contracting, data ownership (licensing), common specifications, computer server and network capacity problems, enterprise buy-in to remote sensing, and data sharing within the organization.

## STATE DOT PRESENTATIONS

Representatives of 15 state DOTs were present at the roundtable, and 14 gave presentations and prepared short summaries of their programs. Copies of the state papers can be found at the University of California, Santa Barbara, NCRST website, www.ncgia.ucsb.edu/ncrst, under Meetings. In alphabetical order, the states represented at the roundtable were

1. Arkansas
2. California (no presentation)
3. Florida
4. Iowa
5. Kansas
6. Maine
7. Maryland
8. Massachusetts
9. Minnesota
10. North Carolina
11. Oklahoma

12. Pennsylvania
13. Utah
14. Virginia
15. Washington

From the 14 state presentations and the subsequent discussions, a number of topics were raised to focus the discussion:

- State of the practice of remote sensing and spatial technologies,
- New initiatives,
- Types of partnerships evolving with states and others,
- Barriers to implementing remote sensing, and
- Issues for further discussion and research.

## State of the Practice of Remote Sensing and Spatial Technologies

Digital photogrammetry, geographic information systems (GIS), and the Global Positioning System (GPS) represent the state of the practice in state transportation agencies. Only one state (Virginia) reported on the integration of remote sensing [light detection and ranging (LIDAR)] into everyday activities. Six states have some ongoing activities related to LIDAR, and three states have projects involving satellite imagery (IKONOS and Landsat7).

## New Initiatives

Experimentation at the state level is common. A total of 29 new initiatives are included in the state write-ups. As mentioned, six involve LIDAR, and three involve satellite imagery. Many of the new initiatives are taken in coordination or partnership with other agencies. Internal new initiatives are generally in the areas of data sharing and data accessibility.

## Types of Partnerships Evolving with States and Others

One of the major drivers in the progression of new technologies is partnerships. Different types of partnerships were mentioned, including partnerships of

- State and county or counties,
- State interagency or statewide agencies,
- State and federal agencies,
- State and university,
- State and private sector data providers and utilities, and
- Combinations of the above.

## Barriers to Implementing Remote Sensing

The following were identified as barriers to implementation of remote sensing technologies in state DOTS:

- Funding, including budget and staff reductions—the most frequently mentioned barrier;
- Time pressures to produce work on a known schedule and lack of time to investigate new ideas;
- Lack of agreement on common formats;
- Lack of understanding and buy-in from staff and top management;
- Data size, data sharing, and data retention related to server and network capability; and
- Licensing.

## Issues for Further Discussion and Research

### *Marketing*

Documenting and marketing successful applications of remote sensing information are needed. A number of possible venues were suggested for this, including state transportation conferences, state GIS conferences, and regional meetings between state DOTs and user groups. Marketing should be designed for three audiences: users, practitioners, and policy makers.

### *Accuracy*

There is a need to sit down with the ultimate users of information to determine the level of accuracy required and to match the required level to the most cost-effective method of data collection. There is a sense that the current accuracy requirements are more traditional and not based on detailed trade-off analyses (trading of accuracy for advantages of time and cost).

### *Partnerships*

Most of the successful projects involving remote sensing have come through some kind of partnership. States need to continue to explore partnership arrangements with a variety of different groups.

### *Time Pressure*

The pressure faced by states to reduce the time from planning to construction is both a barrier and an opportunity. It is a barrier, because the photogrammetry sections are under time pressures to produce products with known accuracy on a predictable time schedule, leaving little time for experimentation. States do not have time to make mistakes. It is an opportunity, because if it can be shown that remote sensing can speed up the project delivery schedule, agencies would be willing to invest in the technology.

### *Measuring Benefits*

There is a need for good information on the accuracy and benefits of using remote sensing data in the project development process. Several side-by-side comparisons are under way that will help provide this needed information.

### *Private Vendors*

Several vendors are proposing complete data packages with remote sensing techniques. States need help in evaluating these proposals and need to share information on their use.

### *Remote Sensing Applications*

To date, the use of remote sensing information in state DOTs has been limited to right-of-way appraisal and acquisition, wetlands mapping, preliminary design, and detail design.

### *Data Sharing, Data Integration, and Data Fusion*

Experience is showing that remote sensing information is usually not stand-alone information. It must be fused with other data to both calibrate and complete the data set. This raises a number of compatibility issues, including for multiple data, multiple projections, and documentation (metadata).

### *Intermodal and Multimodal*

To date, most of the reported development of remote sensing applications has been in the highway project development process. A number of desirable applications could be pursued in the intermodal and multimodal arena.

### *Funding for Remote Sensing*

Funding is an issue raised by most states in their reports. Since most funding for remote sensing information currently comes from project sources, there is a concern that the use and needs for other transportation purposes are not being considered. Planning and MPO needs were examples cited. Remote sensing information may also be valuable for facilities management as well as for facility design.

### *Regulatory Agencies*

There is a concern that regulatory agencies may not accept information coming from remote sensing sources.

### *National Security*

The events of September 11, 2001, have changed the balance between the privacy of information and the desire to develop information databases that can be readily shared. No one can currently predict where the balancing point will ultimately rest. Again, this issue can be both an opportunity and a barrier for remote sensing.

### *Utilities*

States have a number of issues when dealing with utilities on remote sensing projects, including accuracy and liability. Georgia appears to have developed a cooperative program with its utility.

### *Staffing*

Most states have problems training staff in new techniques and retaining the staff. Many states are outsourcing data collection, and existing staff need training in contract specifications and contract management.

### *Computer Networks*

Issues arise on the capacity and speed of servers and networks in handling the large amounts of data that come from remote sensing sources. Dealing with these issues must be part of the equation when considering using remote sensing data.

## Next Steps

In the summary of the meeting next steps were suggested for states to take on remote sensing, which included the following:

1. Continue to look for partnerships and continue to participate in the current RSPA research effort with the university consortia.
2. Use the new AASHTO task force on spatial information and the existing Transportation Research Board (TRB) committees to share information and advance the state of the art.
3. Pursue pooled-funded studies through AASHTO.
4. Conduct additional regional meetings similar to the one held this summer among Minnesota, Iowa, and Wisconsin.
5. Create a website and discussion forum.
6. As part of the 2003 reauthorization of the Transportation Equity Act for the 21st Century (TEA21), ensure that remote sensing is sanctioned and that funding is provided for demonstrations and other activities to advance the state of the practice.

## State Presentation Summaries

### Arkansas

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The following is a brief overview of the use of remote sensing and spatial information by the Arkansas Highway and Transportation Department (AHTD). Also included is information related to efforts by other state government agencies as it pertains to AHTD.

#### *Current Programs and Funding*

AHTD funds

- Photogrammetry; and
- GPS with extensive use of both static and real-time kinematic (RTK)
  - Continuously operating reference stations (CORS)
    - Three AHTD, and
    - 5 min. additional scheduled; and
  - One cooperative National Geodetic Survey (NGS).

State agencies with county government participation fund the development of a statewide GIS that is accessible on the web with spatial data that includes aerial photography, geology, soils, cadastral, census, centerlines, critical infrastructure, geodetic control, government unites, hydrography, land use and land cover, digital orthoimagery, the Public Land Survey System, telecommunications, transportation, and vertical control.

#### *New Initiatives*

The State of Arkansas is implementing GIS. This is upgrading of positional accuracy roadway centerlines for the GIS base maps. This has been requested by utility locators (Arkansas OneCall) so they can better determine the location of a specific utility. The desired precision is ±5 ft. However, survey-grade RTK (GPS) is not considered practical. A pilot project is under development using digital orthorectified quarter quadrangles (DOQQs) to digitize positions; ground truth with some level of GPS; and warping of other existing mapping data produced by AHTD to that map.

AHTD is scanning AHTD aerial photography and making it available on the state GIS website.

#### *Strategies*

- Centerline accuracy upgrade. Public and private teams can perform the testing and develop an implementation plan from the results, if the upgrade is successful.
- Implementation teams. Participation in the federal I-Team Initiative addresses the institutional and financial barriers to the development of the National Spatial Data Infrastructure (NSDI). It aims to offer a coherent set of institutional and financial incentives to make it easy for all levels of government and the private sector to collaborate in the building of the next-generation framework data.

#### *Partnerships*

AHTD is outsourcing county mapping aerial photography.

#### *Barriers*

Barriers to using remote sensing technology in Arkansas are

- Funding,
- Staffing,
- Time,
- Involvement of multiple disciplines with multiple formats and reaching agreement on the ultimate format displayed,
- Time and staff for investigating newer remote sensing techniques such as LIDAR,
- User issues,
- Data accessibility, and
- Proper usage of data.

### Florida

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#### *Current Programs and Initiatives*

1. State aerial photography and photogrammetric mapping program
2. County general highway mapping (mapping of land use and land cover has been eliminated)
3. Generation of spatially correlated multipurpose and seamless GIS base maps for Florida research project, with airborne laser swath mapping (ALSM) and automatic data processing (ADP)
4. GPS statewide network

### *Funding for Remote Sensing and Spatial Information*

1. Federal, state—approximately $2 million
2. Federal Highway Administration (FHWA)—approximately $0.5 million for county mapping
3. State—$10.5 million under a 5-year contract started in 1999
4. State—$3.7 million, originally for a 5-year project started in 1997

### *New Initiatives and Drivers*

1. Digital photography and digital photogrammetric mapping program driven by technology changes and digital product demand
2. Improvement of digital county-mapping processes driven by internal management
3. Evaluation of remote sensing tools and technology for applicability and business decisions
4. None
5. RCI program improvement initiative

### *Successful Strategies*

1. Photography and county mapping program cost–benefit study completed June 2001
2. Outsourcing of county map field verification activities
3. To be determined (TBD)
4. TBD
5. TBD

### *Partnerships*

- FHWA, NGS, National Oceanographic Association of America (NOAA), National Weather Service (NWS), and the Federal Aviation Administration
- Florida Department of Environmental Protection, Florida Department of Revenue, Florida DOT, Florida Department of Management Services, and other state and local agencies
- University of Florida

### *Barriers to Implementation*

- Budget cuts and staff reductions
- Lack of remote sensing technology marketing within the Florida DOT
- Buy-in from key internal customers and executive management
- Lack of education
- User issues
  - –Unfamiliarity with remote sensing tools and technology
  - –Data usability, accuracy, and timeliness issues
  - –Cost

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The Florida DOT has several ongoing initiatives related to the use of remote sensing to improve business processes. This report summarizes the activities surrounding improvement of the collection of transportation data. It will discuss an overall statewide effort and several pilot projects that support the goal of improving the accuracy of transportation roadway feature data.

Roadway feature and characteristic data are collected in several areas of the department to support critical project development and operations management functions. Examples of these types of data include traffic lane width, pavement condition, traffic signs, and shoulder types. Most of these data are currently collected in the field, and their useful accuracy is relative to their application. The accuracy is acceptable for some preliminary design work, maintenance, planning, and traffic operations uses, but not sufficient for roadway design or survey work. At the same time, aerial photography is being flown for several purposes across the state, and the potential for redundancy in this effort is great. Therefore, the Planning group and Survey and Mapping group joined together to establish a task team. The mission is to investigate the potential for collecting data in the planning stages at an accuracy level suitable for preliminary design work. Other benefits include more accurate and easier-to-collect data for maintenance operations as well as the ability to improve GIS base maps through accurate centerline extraction. The benefits of the overall effort include improved data integration, reduced redundancies in data collection, safer data collection, wider use of data, and therefore increased efficiency in production and potential long-term cost savings.

The intent of the task team is to make recommendations to executive management on how remote sensing should be used to collect data in the planning area. This will expand to be applicable also to data collection in maintenance, traffic operations, and safety offices. The main activities of the task team are

1. Investigation of issues such as data accuracy needs. This is being accomplished by working closely with data customers such as environment, project development, and design engineers.
2. Investigation of the need for a system to store and provide access to all potential aerial photography and associated data.

3. Management of several statewide pilots. Data are collected at the district level, so district involvement in the investigation of methods is critical. Several district pilots have started that involve developing applications to extract feature data from existing aerial photography. The most noteworthy pilot started before the involvement of the central office, in the district that comprises 16 counties in the Florida panhandle. They currently use remote sensing (2000-ft aerial photography, color film, *x, y, z* specification accuracy not greater than 6 in., and 3.4-in. resolution) to collect 31 roadway inventory office and field features—all from a desktop PC in stereo (three-dimensional–*x, y, z*) mode. Videologs are also integrated with the software tools. They have linked their linear referencing system (mileposts) with the GPS coordinate system (*x, y, z*), and they produce an accurate centerline that accommodates the vertical and horizontal undulations of the roadway. The accuracy of the field features is anywhere from 2 to 6 in. in *x, y, z*. They have also initiated a pilot program to see if other units in the district (maintenance, construction, traffic operations, safety, design, environmental management, emergency operations, production, right-of-way, public transportation, and bridge structures) can use the data. Several units are very interested in the software tools and methodology. This pilot has been presented in several statewide forums along with the statewide task team efforts, and the concepts have been well received.

The department is also involved in an NCRST project to investigate the feasibility of using commercial remote sensing technologies with GIS mobile mapping and GPS to develop accurate and comprehensive databases of roadway features and characteristics. The project will make recommendations on the cost–benefit applicable to Florida's data collection process. It will also make recommendations applicable to other states.

All the above work will be completed next year. It will allow the Florida DOT to successfully move ahead and begin incorporating new standards for data collection based on remote sensing technologies.

## Iowa

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The Iowa DOT has several remote sensing projects under way. The projects include initiatives to obtain, distribute, and analyze remotely sensed data. Other remote sensing projects that the Iowa DOT has been involved with are also included in this summary.

### *Internal Initiatives*

#### *LIDAR*

The Photogrammetry Section acquired LIDAR data for a project on US-30 in Linn, Cedar, and Clinton Counties, from the Lisbon Bypass to the city of DeWitt. The project includes seven bypass areas. The corridor covered 26 $mi^2$ across hilly terrain. LIDAR data was acquired to evaluate the potential benefits of this technology throughout the highway corridor development process. The LIDAR was flown at 3,000 ft above ground in June 2001. LIDAR deliverables were

- MicroStation files with 10-ft digital elevation model (DEM) generated from the LIDAR and breaklines;
- MicroStation files of the LIDAR bare ground DEMs that were generated from raw LIDAR data modified by software to remove the vegetation canopy; and
- American Standard Code for Information Interchange (ASCII) files containing bare ground LIDAR data that were generated from raw LIDAR data modified by software to remove the vegetation canopy.

The intent is to use this information to evaluate various alignments and establish a final alignment along the 45-mi corridor. The selected alignment will be reflown at 2,000 ft, and detailed photogrammetric and field survey information will be added to the LIDAR data for the final design phases. The Iowa DOT will compare the LIDAR and photogrammetric products.

#### *Image Cataloging Web System*

The Iowa DOT is acquiring a large amount of digital aerial photography for planning and engineering. Often the same imagery was obtained by different parts of the department and was redundantly stored on department computer systems. The Iowa DOT developed a system, under the guidance of its Aerial and Satellite Imagery Task Force, to acquire, catalog, and distribute aerial photography. The U.S. Geological Survey (USGS) DOQQ and digital raster graphs (DRGs) were obtained in georeferenced digital files in tagged image file format. The files were reprojected and compressed to make them more usable in a production environment. Each file was then spatially cataloged by an automated process, and a GIS-enabled web page was developed to query available imagery. Higher-accuracy imagery from individual counties and from the Iowa DOT Photogrammetry Section is also being included in this image catalog.

#### *Acquisition and Evaluation of IKONOS Satellite Imagery*

Iowa DOT contracted with Space Imaging to obtain 1-m resolution digital imagery of a wetland mitigation bank area. The imagery was obtained from the IKONOS satellite in summer 2001. The 1-m panchromatic/4-m-color bundled product was purchased, and imagery was obtained in four bands: near infrared (NIR), red (R), green (G), and blue (B). The project is 700 acres in size. The plan is to use the satellite imagery as a seamless overhead view of the project area and also to perform some simple analyses of the project area using the spectral bands. Specifically, the presence of hydrology, wet soils, and wetland vegetation will be looked for to learn what general trends can be observed from this type of imagery. Another application of the data will be change detection. The Iowa DOT will be able to remotely monitor the site and, along with some ground truthing, quickly determine the changes in vegetation and hydrology over time. This could produce significant cost savings over a large area.

### *Projects External to DOT*

*Acquisition of New Statewide Imagery*

The Iowa Geographic Information Council Remote Sensing Committee, under the leadership of the Iowa Department of Natural Resources, is developing partnerships with federal, state, and local governments and the private sector to secure funding and requirements for acquisition of new statewide aerial imagery. The primary product will be second-generation color infrared (CIR) DOQQs that will be certified by the USGS. Additional products will include panchromatic images generated from the CIR image and compressed format imagery for more efficient general use with Internet and network applications. Funding has been secured for the project, and a contract is being negotiated. The Iowa DOT is partnering in this process by providing funding and technical support.

*University of Northern Iowa*

Remote sensing is one part of the University of Northern Iowa (UNI) Science center for Teaching, Outreach, and Research on Meteorology (STORM) project. Under this project, UNI has provided a 2-week short course on remote sensing, acquired and distributed ERDAS imagery on its website (www.uni.edu/storm/), and provided other teaching, outreach, and research related to remote sensing.

*Iowa State University GIS Support and Research Facility*

Iowa State University (ISU), in partnership with the Massachusetts Institute of Technology and Natural Resources Conservation Service, developed the Iowa Geographic Image Map Server. This server provides Iowa Landsat, DOQQs, and other imagery to the public. The server merges image tiles and provides output to users in several different resolutions and formats (see ortho.gis.iastate.edu/).

### *DOT Research Partnerships*

*ISU Center for Transportation Research and Education*

The ISU Center for Transportation Research and Education has worked with the Iowa DOT on several remote sensing projects. Projects include assessments of

- Aerial photography for parking and travel demand validation;
- Aerial photography for collecting data elements for our linear referencing system;
- Stereo video-logging imagery for identifying roadside features;
- Aerial and satellite for collecting inventory and access management;
- LIDAR for location studies and preliminary design; and
- LIDAR for highway safety studies, bridge and culvert flooding risk, and pavement performance evaluation.

*Mississippi State University*

Mississippi State University and the Iowa DOT are cooperating in a hyperspectral remote sensing research experiment. The research focuses on helping to solve environmental issues with remotely sensed hyperspectral data. Of particular interest are wetland-related issues frequently encountered during the development of transportation corridors.

## Kansas

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### *Issue*

Participation in purchase of up-to-date remotely sensed Earth imagery data.

### *Indication of Issue's Existence*

Imagery presently used is outdated (1991). Current, up-to-date data are needed for applications and for taking advantage of newer technologies.

### *Other Background Information*

Examples and users of identified categories of imagery applications include

- Analysis and evaluation—corridors and accident locations, and discovery phase applications—for traffic engineering, transportation planning, and design sections;
- Data validation—state system, nonstate system, and rail networks, and GPS points—for transportation planning, design sections in coordinating and traffic engineering;
- Data capture—networks and inventories for transportation planning and local projects sections for design and coordinating; and
- Visualization—for public involvement and litigation for public involvement and chief counsel sections.

Selection criteria for imagery purchase, all of which affect cost, can include

- Capture device (type of camera) and source (airplane versus satellite);
- Spatial resolution (fineness of image detail);
- Accuracy (proximity of an object in the image to its actual location);
- Age of data and update and maintenance schedule;
- Type of imagery [black-and-white (B/W) versus multispectral];
- Size (area of coverage);
- Storage location (data storage and serving of data will occur at the Kansas Data Access and Support Center);
- Licensure, ownership, and distribution;
- Value-added services such as geocoding, orthorectification, and network digitizing; and
- Cost sharing with others participating via the GIS Policy Board.

### *Options*

1. Use 1991 imagery data and use traditional methods to fill data gaps.
2. Elicit Requests for Proposals from vendors (GIS Policy Board).

### *Recommendation*

Option 2.

### *Fiscal Impact*

Cost ranges from $1.3 million to $8.5 million. The Kansas DOT share would be 50% of total cost, not to exceed $650,000 for initial purchase. The other 50% would be provided by the GIS Policy Board and from non-Kansas sources such as the National Aerial Photography Program (NAPP), the Natural Resources Conservation Service, and USGS.

### *Policy Impact*

A positive impact to the Kansas DOT will be realized. The enterprise approach provides opportunities for use of a common, standardized data source for unified GIS development, applications, and solution building and could yield the synergy that results from a collaborative effort.

## Maine

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In late 1999, the Maine DOT started working with the Technology Service Corporation (TSC) in the Commercial Technology Applications Program in Support of the Department of Transportation Program on Remote Sensing Applications in Transportation (DTRS56-00-BAA-0005). The partnership was created to investigate remote sensing applications that could assist Maine DOT in determining possibilities for alternative route locations for new highways and also to automatically update road networks within the GIS system with remotely sensed information.

The primary research involves the automation of route location analysis and cost estimation, which are done by highway engineers when determining corridors for new highway location studies. The Maine DOT uses traditional methods of route determination. These methods are time-consuming and labor-intensive and involve the possible use of USGS quad sheets, aerial photogrammetry, national wetland information, and other existing paper and electronic data. TSC's research involves the use of current IKONOS imagery, USGS digital terrain elevation data (DTED), and National Land Cover Dataset information. Aerial photographs and specific user cover layers can also be incorporated into the program that has been created. A result of the work of Steven Jaroszewski and the TSC team is an astonishing program that can automatically generate highway corridors using the above-mentioned layers and also generate the cost estimates for constructing the highway, purchasing the rights-of-way, mitigating wetlands, and building bridges.

Maine DOT provided TSC with basic information about the existing Brewer/Holden I-395 extension project that is being developed traditionally by Maine DOT and its consultants. TSC was shown the takeoff point and was tasked with providing highway alternatives that would either upgrade the existing highway network or create a new highway connecting I-395 to Route 9. During a recent presentation to the Maine DOT, TSC's Steven Jaroszewski was able to automatically generate, with the developed software, highway corridors that very closely resembled the corridors that had taken the consultant engineering firm months to develop. In addition to the corridors, the program also generated cost estimates for each alternative. When Maine DOT changed parameters of the base information, the program was able to create new data within minutes. The results of this research could revolutionize the way highway location studies are accomplished in the near future. Mr. Jaroszewski will be presenting the results of the study during this TRB meeting with NCRST.

Maine DOT is also involved with using airborne GPS photogrammetry for all of its new photogrammetric mapping projects and using aerial photography layered with design data for presentations at public hearings. The photogrammetry unit is working with the public hearings unit to merge USGS DTED data, detailed survey and design information, graphic information, and aerial photography to create drive-through and fly-over presentations for public hearings on planned highway construction. The department has investigated the use of close-range laser survey technology for bridges and is looking into the potential of close-range digital photogrammetry for bridges. The photogrammetry unit has begun to look toward LIDAR information for a large project that needs only digital terrain data to study the hydrology.

The utilities section of Maine DOT is working on a subsurface utility engineering (SUE) pilot project to accurately identify the location of underground utilities. As a side benefit, they were able to verify the accuracy of ground penetrating radar (GPR) that was demonstrated within the limits of that same project a couple weeks earlier. The data are now being processed, and the reference points are being located by survey. Shallow gas and telephone lines were among the findings. In several areas, the consultant working on the SUE pilot project showed where the marks provided by the utility, or its contracted locator, were off by several feet.

## Minnesota

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Minnesota is experiencing a program spike because of special funding for Inter-Regional Corridor initiatives. In FY 2001 $3.0 million was invested in photogrammetric products and services. It is anticipated that $2.8 million will be invested in FY 2002. Internal Minnesota DOT (MN/DOT) resources consume approximately 30% to 34% of this budget; the balance is outsourced to private partners.

### *New Initiatives and Drivers*

MN/DOT continues to migrate from analytical to digital photogrammetry. Three soft-copy workstations have been added to the equipment arsenal in the last 24 months: 1 Z/I Imagestation IV, 1 LH Systems DPW (NT), and 1 Z/I stereo soft kit (SSK) system. Orthophoto production now accounts for almost 25% of MN/DOT's photogrammetric product market. MN/DOT will make another significant investment in digital photogrammetry in the next 90 days by purchasing a photogrammetric scanning system.

Coarse DEMs are being introduced to hydraulic, planning, and preliminary design personnel. MN/DOT has completed 13 DEMs using LIDAR technology. Test data for these projects are anticipated this winter in accordance with the National Standard for Spatial Data Accuracy.

MN/DOT information technology support staff recently installed a multiterabyte server with fiber links to two of the digital workstations to satisfy the large memory appetite of digital projects. The next installation of fiber links to mass memory will be added to the scanning system and SSK system.

### *Successful Strategies*

MN/DOT is currently outsourcing a larger portion of work to private partners to meet current program delivery expectations. Senior technical personnel within the photogrammetric unit have been realigned into a new technical specialist class and are helping to oversee the consultant program. The new technical specialist positions are primarily technical, with added project management duties.

MN/DOT has recently produced a product poster to educate users about available photogrammetric products, including information on their accuracies, costs, and lead times.

### *Partnerships*

A countywide orthophoto and a digital terrain model (DTM) are being used to support a 2-ft contour interval (CI) in Washington County. Opportunities for collaboration also exist in Ramsey, Hennepin, Olmsted, and Chisago Counties and possibly others.

The Minnesota Department of Natural Resources has recently brought together many government agencies in the state to investigate the idea of developing a Minnesota 2-ft statewide DEM. This initiative is still very preliminary but could have huge positive implications for photogrammetry and remote sensing in the state. A statewide

2- to 4-ft DEM would open the door for many remote sensing projects that are otherwise cost-prohibitive or too intimidating to potential users.

### *Barriers to Implementation*

Funding is a barrier to implementation. Decision makers who are in the heat of the program delivery battle for the control funds for photogrammetric products. The process forces decision makers to worry about today's program, leaving them potentially unaware of the benefits of investing in products that could help future projects. In addition, the needs of facilities management are perceived as lower priorities than the needs of program delivery.

### *User Issues*

The MN/DOT photogrammetric unit is designing a corridor-mapping strategy in lieu of the existing project-specific program. The concept proposes aerial photography collection at the corridor level and assembly of products of value to facility management, GIS, planning, and preliminary design personnel. The corridorwide products would be designed to carry MN/DOT through the project's construction limit phase. With additional vertical control, they would also be suitable for detail design mapping. The big picture is to have a product on the shelf in probable locations to establish construction limits and allow concurrent production of mapping for the detail design level. The increased investment would minimize project start-up time and allow photogrammetric data to be used by other disciplines before the terrain is changed and the aerial photography becomes outdated.

## North Carolina

Keith Johnston, *Highway Design Branch, Photogrammetry Unit, North Carolina Department of Transportation*
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The North Carolina DOT (NCDOT) is participating in the USDOT Project DTR56-00-T-0011, entitled Airborne Sensor Fusion: A Fast-Track Approach to NEPA Streamlining and Environmental Assessment, with private and university sector partners. EarthData International is coordinating the study effort and has partnered with NCDOT, ITRES Research Limited, and Mississippi State University. The goal of the study is to demonstrate where remote sensing technology can be used to expedite environmental studies, transportation planning, preliminary design, and permit approval.

Remote sensing in the study included acquisition of hyperspectral image data, of GPS and inertial measurement unit (IMU)–controlled B/W film aerial photography, and of LIDAR terrain data. ITRES Research Limited acquired 14-band 1-m resolution and 11-band 60-cm resolution hyperspectral image data with its Compact Airborne Spectrographic Imager (CASI) system in June 2000. EarthData International acquired leaf-on LIDAR terrain data in June 2000 and leaf-off LIDAR terrain data and GPS/IMU controlled aerial photography in March 2001. Mississippi State University is fusing several of the data sources in an effort to delineate wetlands for the project study area.

Product deliverables include 25-cm resolution digital B/W orthophotography; 1-m resolution natural color, CIR, and classified digital orthophotography; bare earth LIDAR terrain data; GPS and IMU control data for the B/W aerial photography; and wetland delineation based on the classified hyperspectral imagery and collateral sources.

NCDOT's role in the study was to provide in-kind contributions for analysis and evaluation of the deliverable products. NCDOT selected Transportation Improvement Program (TIP) Project R-2606 in Randolph County near High Point for the study project. When discussions began for undertaking this study, the R-2606 project corridor had already been selected, and preliminary design was nearing completion. Topographic mapping was available to use in the data evaluation process, and surveys for final design for each portion of the project were scheduled. Field wetland delineation data had already been collected and were also available for comparison. Many of these data were utilized in the deliverable product evaluation.

EarthData International delivered the majority of the products in late September 2001. NCDOT staff have concentrated their efforts on performing tests of the bare earth LIDAR terrain data with ground and photogrammetric survey data for comparison. Some results of these comparisons are

- Approximate 12- to 15-cm elevation bias and 11- to 13-cm elevation random error on natural ground surface; and
- Approximate 34- to 44-cm elevation bias and 3- to 6-cm elevation random error on paved roadway surface.

It was also found that contouring with bare earth LIDAR terrain data is improved with the addition of breakline data, and bare earth LIDAR terrain data volumetric quantities matched final mapping quantities within 2% for an 11,000-m segment of the R-2606 project.

Mississippi State University has been using the classified hyperspectral imagery, hydrologically corrected terrain data, and soils data to predict wetland locations. Work on this portion of the project is still under way.

NCDOT's goal for the study was to obtain vector wetland delineation polygons from these remote sensing techniques. This has not been realized to date.

Issues that NCDOT sees with using LIDAR terrain data for transportation preliminary design involve understanding its accuracy over different surface covers and conditions, computing and storage, and the cost scalability to the size of typical transportation corridor study projects.

Other remote sensing activities in North Carolina include the North Carolina Floodplain Mapping Program (NCFMP), a multiyear program to produce Flood Insurance Rate Maps (FIRMs) statewide. The state of North Carolina, through the Federal Emergency Management Agency's (FEMA) Cooperating Technical Community partnership initiative, has been designated as a Cooperating Technical State, meaning that North Carolina will assume primary ownership and responsibility for its FIRMS.

As part of a program to update and maintain FEMA FIRMs, NCFMP has employed LIDAR technology and conventional photogrammetric survey methods to collect, process, and conduct quality control on full-coverage, statewide elevation data. The work is prioritized by river basins, of which North Carolina has 17. LIDAR data have been collected in six eastern river basins and are currently being processed and validated for accuracy. This territory is approximately 24,000 mi$^2$ and includes the river basins of Lumber, White–Oak, Tar–Pamlico, Cape Fear, Neuse, and Pasquotank. Delivery of the initial data is expected over a period of several months beginning in January 2002.

Collection of elevation data for subsequent river basins is subject to continuing state budget appropriations and cost–share contributions from other sources.

## Oklahoma

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The Geographical Resource Intranet Portal (GRIP) is a web browser application that provides easy access to Oklahoma DOT business data through a map interface. GRIP is being developed as a 3-year project, with the first year focusing on 8 different business layers, 32 different map themes, and statewide access to digital imagery. GRIP is an intranet application and therefore is only available to users with access to the Oklahoma DOT computer network.

GRIP was developed to provide a single source by which transportation professionals could retrieve information needed to make better decisions. The geographical component of GRIP helps in the quick visualization of relationships between data and projects. By providing easy access to information, maps, and digital imagery, the GRIP application will enable quick responses to internal and external information requests.

## Pennsylvania

L. Bradley Foltz, *Photogrammetry and Survey Division, Bureau of Design, Pennsylvania Department of Transportation*
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The Pennsylvania Department of Transportation (PENNDOT) is working with the NGS to develop Harrisburg International Airport as a test site for LIDAR.

### *Geodetic Surveys*

PENNDOT operates four CORS sites and is installing two new sites. This will give the department statewide coverage. PENNDOT is setting up a test Virtual Reference System south of Pittsburgh. If preliminary testing goes well, the system will be expanded statewide.

In the past 2 years, all district survey crews have been outfitted with RTK GPS and robotic and reflectorless total stations.

PENNDOT is operating two Cyrax scanners to provide the state with high-density, three-dimensional modeling capabilities for structures that are difficult to survey and land features such as expansive bridges, rock face walls, historical buildings, and limited roadway surfaces.

### *Administration*

PENNDOT has completed Phase 2 of five phases of its web-based archival and project management system. This will give customers easy access to photo and survey information. See the website www.penndotpams.org (log in as "user" with password "pams").

The Pennsylvania Department of Conservation and Natural Resources, as part of the National Map Project with USGS TopoGeo, is putting together a seamless digital map at 1:2400, 2-ft CI. The department is also working with NASA to start a LIDAR and radar project.

The state's Department of Environmental Protection has purchased colorized 10-m SPOT data.

## Utah

Dennis Goreham, *Automated Geographic Reference Center, Utah Department of Transportation*
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Utah has a long history of collaborative development of geographic information related to the state's transportation infrastructure. The goal has always been to cooperatively develop and share the best (most accurate, current, and complete) information about transportation-related themes. This long-term effort was further defined and focused in the Data Sharing Memorandum of Understanding (MOU) signed by Governor Mike O. Leavitt and nine federal agencies in October 1998. This MOU specified that "the participating agencies agree to share data for mutual benefit, in order to minimize duplication of efforts and expenditures, and to enhance intergovernmental cooperation." The current projects that contribute to the ultimate goal of a state comprehensive transportation database are briefly described below.

### *1:24,000 Single-Edition Quad Mapping*

In 1995, the state of Utah and USGS signed an agreement to cooperatively fund the development of a Utah transportation database derived from published 1:24,000 maps. The Forest Service has since joined this collaborative effort. Initially all 1,540 quad sheets were digitized. Because these published maps average 23 years in age, a revision process was began in 1998 with digital orthophoto quads and NAPP photography. Approximately 700 quads have been revised to date. Starting with the revisions done in 2000, GPS data acquired by the counties were incorporated into the product. The Forest Service is working with the counties to include roads they have placed in GPS that are to be shown on future published maps.

### *RS2477 Inventory Project*

Starting in 1999, the counties have been funded to participate in the RS2477 Rights-of-Way inventory and mapping project. Although a few counties had begun the inventory before they received the funding, most of the work has been done over the last 3 years. Almost $3 million has been distributed to the counties so far. All rural counties have received funding to purchase necessary equipment, hire additional personnel, and receive training and technical assistance. In return, they are to create data compliant with the Utah Transportation Data Model and make those data available to the Utah State Geographic Information Database (SGID) for general state uses. The counties have been focusing on Class B and D roads, which make up the majority of the roads in rural counties.

### *Federal Aid Eligible Routes*

The Utah DOT distributes funds for state Class B and C roads. The counties submit reports annually for their share of these funds. Utah DOT spot-checks reports by placing some of the routes in its GPS, but typically completes coverage within small areas. The Utah DOT has completed placing in GPS several hundred miles of Class B and C roads, which it will make available to the Automated Geographic Reference Center (AGRC) for related projects.

### *State and Federal Routes Mapping*

The Utah DOT has mapped into the GPS all Class A state and federal routes in Utah, representing approximately 10,000 mi of the state's estimated 125,000 mi of roads. This also will be available to AGRC for related projects.

### *County 1:100,000 Sheet Maps*

The Utah DOT maintains 96 cartographic products, at 1:100,000 scale, representing the roads in the state. These maps currently use the transportation features from the SGID, but Utah DOT would like to start incorporating the GPS data from the counties and the cities.

### *Bureau of Land Management Resource Management Plans*

The Bureau of Land Management was appropriated $19 million nationwide to update its Resource Management Plans. Several of these are in Utah covering all or parts of the east central counties. Next year, the bureau will move to resource management areas south and west from these. Part of the planning process includes improving the GIS data the bureau uses. It is working with the counties to procure the best available transportation data for these plans.

### *National Map Pilot Project*

USGS has initiated a new program to develop a national database for framework layers, including transportation. One urban (Salt Lake) and one rural (Grand) county will participate. The goal is to transactionally update this national database from data generated by state and local entities as change occurs. This database will be the primary source for all federal agency geographic information needs.

### *TIGER Modernization*

The U.S. Census Bureau is beginning a process to increase the accuracy and currency of its topologically integrated geographic encoding and referencing (TIGER) database. Again, because of Utah's lead in digital transportation data, it has been asked to participate as a pilot on this initiative also. Utah is to identify one county that has complete data on road coordinates and attributes for testing the Census Bureau's modernization and attribute conflation processes.

### *Statewide Addressing Project*

This is the most comprehensive of all the state's current transportation-related activities. The state of Utah, Blue Stakes, the Census Bureau, USDOT, Utah DOT, and Comprehensive Emergency Management have initiated an effort to create a high-accuracy road centerline (with addresses) database for the state. This will initially be used for an application for utility companies, AOne Call@ notification. Its use in aiding local enhanced 911 (E911) emergency efforts is also anticipated.

Utah has no central source for E911 data coordination. Because of the method of funding distribution, local E911 providers develop their own standards and procedures. Currently there are no standards for addressing or for the geographic data needed for emergency vehicle routing. This project, funded by USDOT and the state of Utah, will use the most accurate road coordinates available, fully attributed to the Utah Transportation Data Model. It will benefit the AOne Call@ system, E911, wildfire efforts, and many other applications of a complete transportation database.

## Virginia

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The Virginia Department of Transportation (VDOT) formed its own photogrammetric unit in 1957. Since those early days, and for the past 40-plus years, the department has operated a very traditional photogrammetric unit. Remote sensing techniques have been incorporated in our everyday activities since 1957. Today, VDOT utilizes satellite and airborne imagery for many of its projects and has recently employed LIDAR as another remote sensing tool.

The department's survey unit initiated its first LIDAR project in 1998 to determine the adequacy of these data for a route location study. The project was located in the mountainous and heavily wooded terrain of southwest Virginia. Because of the steepness and ruggedness of the terrain, GPS-controlled photography was utilized to produce stereo models for quality checking the LIDAR data. Photogrammetric breaklines were added for all major and some minor breaks, and LIDAR spots were edited as necessary. The majority of the data were derived from LIDAR. Field cross sections were secured in areas not visible by photogrammetric methods.

The survey unit's second foray into LIDAR was for another route location study in southwestern Virginia. This project, which covered 60 $mi^2$, was initiated in summer 2000 and utilized LIDAR with airborne GPS-controlled photography for editing. Requirements included digital orthophotos and a DTM that would support 4-ft contour accuracy. The DTM data, which were field checked, met the project's accuracy requirements.

The department has just completed two more LIDAR projects near Williamsburg. One project was to determine the best approach to widen I-64 from four to six lanes in the historic Williamsburg area, while the other was for the final design of a nearby I-64 section. For the final design project, airborne GPS-controlled photography was utilized to produce stereo models for quality checking the LIDAR data. Photogrammetric breaklines were added for all major and minor breaks. Field survey breaklines were added for hydraulic features. LIDAR spots were closely reviewed and edited within the VDOT right-of-way. Of the point-only data, 90% were derived from LIDAR. To verify the accuracy of the LIDAR and photogrammetry data, 20 field profiles were read. Detailed quality reviews are currently under way to determine if these data meet accuracy requirements for final design.

VDOT will continue to evaluate the latest remote sensing techniques and then determine their role in supporting the department's massive transportation program.

Dan Widner, *Virginia Department of Transportation*
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The Virginia Transportation Research Council and Virginia Commonwealth University have joined for a research project with three goals:

1. Testing technical feasibility of using multispectral imagery for monitoring wetland mitigation sites and areas affected by the presence of acidic soils;
2. Educating state and federal regulatory agencies on the capabilities and limitations of this approach; and
3. Acquiring regulatory approval.

The first goal was completed successfully, and Goals 2 and 3 are in process.

VDOT is now part of a new Technology Application Project (TAP) in conjunction with NCRST–Environment and Mississippi State University. The goal is to demonstrate how multispectral imagery can be incorporated into an enterprise GIS and automated as a viable planning tool for environmental assessment. The subject area is wetland identification for proposed construction sites. The end result will be a cookbook methodology for potential use by other DOTs.

For this, VDOT is starting the third year of a 3-year effort to acquire and implement a new, more accurate and comprehensive statewide centerline file. Digital orthophotography is being used extensively for quality assurance and in some cases (where available) data collection. This involves many data sources, including local GIS data and digital orthophotography, but primarily data are collected by a van equipped with GPS and inertial navigation that gathers photolog information every hundredth of a mile. These data are then developed into centerlines via terrestrial photogrammetric techniques.

At the state agency level, Virginia has an RFP on the street to fly the entire state at 1-in.:200-ft and 1-in: 400-ft scales. VDOT is being consulted for technical specifications as well as being asked to serve on the selection committee.

VDOT sees tremendous potential in the use of remote sensing for asset management, will be following the results of these partnerships, and may be interested in pursuing this further.

## Washington

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The agency supports substantial in-house aerial photography, geodetic survey, and photogrammetry programs that generate all revenue through the sale of products and services, at cost, to customers within the Washington State DOT (WSDOT), other government agencies, and the public. Most work comes from highway and modal projects and typically consists of flying a data collection mission, creating any needed geodetic control network points, then processing the data into three-dimensional MicroStation design files and high-resolution orthophoto mosaics used by project engineers. Photogrammetry is now 100% in soft copy, and airborne GPS is used with the aerial photo platform.

The Washington Remote Sensing Consortium is cooperatively acquiring Landsat7 data from the Earth Resources Observation Satellite (EROS) for the entire state. The funding is arranged as an annual subscription, and then the account is used to acquire regular updates. The current rate is $5,000 per agency, with 16 or 17 federal, state, and local or tribal partners. EROS is producing the first data set. The group is associated with a similar national organization.

The state's Environmental Affairs Office has become one of USDOT's TAP partners with cooperative funding to compare the costs and benefits of using remote sensing technologies for environmental information development with traditional methods, within a highly urbanized corridor that is undergoing programmatic NEPA evaluation. Image fusion will be used to create land use and land cover information from Landsat7 and high-resolution orthophoto data. The $150,000 USDOT contribution is part of a total $438,000 effort.

The Environmental Permit Streamlining Act of 2001 directs the state environmental regulatory agencies to work with WSDOT to improve the permitting process (www.wsdot.wa.gov/eesc/environmental). Using best available information is key to this process. WSDOT is partnering with other statewide efforts to sponsor information sets that fill information gaps. These data are often required by regulatory agencies to get permits approved. This investment in data gets WSDOT credit toward environmental protection. Remote sensing is a key data source and technology for developing several needed information sets, such as current land use and land cover, the built environment, and watershed characterizations. Its advantages are currency and spatial extent (statewide consistency). Most success is expected during early environmental documentation processes such as programmatic corridor analysis. At the project, site-specific stage remote sensing is more challenging, because data collection costs and processing time do not fit into the project schedule or because the technology has problems in certain local site conditions.

## Appendix B

# Conference Workshop Information

### Introduction to Remote Sensing

**Roger L. King,** ***Mississippi State University***
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NCRST–Environment: www.ncrste.msstate.edu

### Successful Public and Private Partnerships for Procuring and Utilizing Remote Sensing Imagery: The Case Study of Pima County

**Val Noronha,** ***University of California, Santa Barbara***
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### The National Map: A Framework for Institutional Interoperability

**Joel L. Morrison,** ***Ohio State University***
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NCRST–Flows: www.ncrst.org/ncrst-f

### Applying Remote Sensing Technology to Airports

**Michael T. McNerney,** ***DMJM Aviation***
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### A Fast-Track Approach to National Environmental Policy Act Streamlining and Environmental Assessment: Technology Demonstration Project

**Karen Schuckman,** ***EarthData Technologies, LLC***
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# Appendix C
# Listing of Technology Buffet Displays

## Mississippi State University Consortium

### National Center on Remote Sensing in Transportation–Environment

- Air Quality Analysis Using Differential Absorption LIDAR
- Regional-Scale Watershed Assessment
- Regional Land Cover Classification and Change Detection
- Assessing the Need for Remotely Sensed Data for Environmental Analysis
- Hyperspectral Remote Sensing for Identification of Wetlands

### Associated Technology Application Projects

- Remote Sensing of Environmental Parameters for Use in Streamlining the NEPA Process, *ICF Consulting,* Gary Erenrich, gerenrich@icfconsulting.com
- Airborne Sensor Fusion: A Fast-Track Approach to NEPA Streamlining and Environmental Assessment, *EarthData Technologies,* Karen Schuckman, kschuckman@earthdata.com

### Other Environmental Application Projects

- Integrating Imagery into the Transportation Planning Process—FHWA Small Business Innovation Research, *Shenandoah Mountain Geographics, Inc.,* Bruce Edward Kiracofe
- NEPA Streamlining the Design of I-69 Through the Upper Mississippi Delta, *U.S. Environmental Protection Agency,* Cory W. Berish

## Ohio State University Consortium

### National Center on Remote Sensing in Transportation–Flows

- Satellite-Based Data: Proof of Concepts and Operational Issues
- Statistical Modeling for Traffic Monitoring
- Needs Assessment and Allocation of Imaging Resources for Transportation Planning Management
- Using Airborne-Based Data in Real-Time Network State Estimation, Prediction, and Management
- Truck Rest Area Availability and Utilization
- Freight and Intermodal Flow Analysis
- Spectral Research Program
- Validation of Remote Sensing Techniques for Traffic Flow
- Traffic Management-Sensor and Platform Issues

### Associated Technology Application Projects

- Remote Sensing Applications in Transit, *Bridgewater State College*
- Road Network Planning Tool, *Technology Services Corporation*

### Other Operations Application Projects

- Applications of Remote Sensing to Highway Operations, *Federal Highway Administration,* Paul Pisano

## University of California, Santa Barbara Consortium

## National Center on Remote Sensing in Transportation–Infrastructure

### Road Centerlines

Using hyperspectral imagery to identify pavement materials; linear filtering to distinguish roads from rooftops; vectorization and postprocessing to create centerlines; data modeling; cost-comparison against Global Positioning System (GPS).

### BridgeView

ArcView extension, presents different scales of imagery and geographic information system (GIS) layers as user zooms in on object of interest; interactive tools allow user to adjust location of bridge with reference to imagery, for compliance with National Bridge Inventory requirements.

### Asset Inventory

Feature extraction from large-scale photography; analysis of department of transportation user requirements; comparison of different scales of imagery and their utility with respect to user needs.

### Airport Layout and Airspace Analysis

Use of light detection and ranging (LIDAR) and digital photography to create orthophotos for airport layout plans and to identify potential obstructions to airspace; fostering cooperation with a regional GIS, digital orthophoto project, and regional data center. *Pima County Association of Governments*

### Associated Technology Application Projects

- Impact of Instant Imagery Access on a Regional Database for Transportation Planning, *Orbital Imaging Corporation (ORBIMAGE)*
- Long-Term Monitoring of Changes in Transportation and Land Uses Associated with the Central Artery/Third Harbor Tunnel in Boston, Massachusetts, *University of Massachusetts, Amherst,* Kitty Hancock

### Other Infrastructure Projects

- Florida Department of Transportation Roadway Inventory Data Collection

## University of New Mexico Consortium

## National Center on Remote Sensing in Transportation–Hazards

### Roadway Risk and Slide Hazards

Interferometric aperture radar (IFSAR)–derived digital elevation model, Landsat imagery, and other remotely sensed data are used to assess the threat of avalanches and slides to transportation infrastructure; automated procedure to assess roadway risks will be demonstrated. *University of Utah*

### Road Network Updating

A semi-automated process to update existing road networks in rapidly developing areas with satellite imagery and aerial photography is demonstrated. *University of New Mexico*

### Rural Road Trafficability and Maintenance

Remotely sensed imagery is integrated with Doppler radar, topographic data, soils, and transportation infrastructure maps to assess damage to roads and related infrastructure resulting from localized rainfall and flooding. The system classifies road segments by surface condition and maintenance requirements, allowing the efficient deployment of maintenance resources following significant rainfall and flooding events. *University of New Mexico*

### Airport Glide Path Obstructions Identification

LIDAR and digital photography are used to identify glide path obstructions in accordance with the National Image and Mapping Agency and Federal Aviation Administration requirements for the Federal Airfield Initiative. *BAE Systems and University of New Mexico*

### Remote Sensing and Evacuation Planning

The integration of remotely sensed data into the Oak Ridge Evacuation Modeling System (OREMS) allows the rapid updating of transportation infrastructure. The use of OREMS for evaluating alternative evacuation scenarios in response to changing road conditions and closures is demonstrated. *Oak Ridge National Laboratory*

### Citations and Annotated Bibliography for Remote Sensing and Transportation

An online comprehensive bibliography of articles, books, papers, and web pages addressing remote sensing and applications for transportation provides a source of recent and historical uses of remote sensing. The ability to search for citations by subject, author, and year is provided in an easy-to-use browser-based environment. Citations can be exported in text delimited, html, and EndNote formats for easy use in other programs and documents. *George Washington University*

## Appendix D
# Abbreviations and Acronyms

| | |
|---|---|
| AADT | Average Annual Daily Traffic |
| AASHTO | American Association of State Highway and Transportation Officials |
| ADAS | Airborne Data Acquisition System |
| ADP | Automatic Data Processing |
| AGRC | Automated Geographic Reference Center |
| AHTD | Arkansas Highway and Transportation Department |
| ALSM | Airborne Laser Swath Mapping |
| ASCII | American Standard Code for Information Interchange |
| ASPRS | American Society for Photogrammetry and Remote Sensing |
| ATR | Automatic Traffic Recorder |
| AVIRIS | Airborne Visible/Infrared Imaging Spectrometer |
| B/W | Black and White |
| CA/T | Central Artery/Tunnel |
| CASI | Compact Airborne Spectrographic Imager |
| CEO | Chief Executive Officer |
| CI | Contour Interval |
| CIR | Color Infrared |
| CNTH | Center for Natural and Technological Hazards |
| CORS | Continuously Operating Reference Stations |
| CTA | Center for Transportation Analysis |
| DEM | Digital Elevation Model |
| DIAL | Differential Absorption LIDAR |
| DIGIT | Digitally Integrated Geographic Information Technologies |
| DMI | Distance Measuring Instrument |
| DOQQ | Digital Orthorectified Quarter Quadrangle |
| DOT | Department of Transportation |
| DRG | Digital Raster Graph |
| DTED | Digital Terrain Elevation Data |
| DTM | Digital Terrain Model |
| E911 | Enhanced 911 |
| EDAC | Earth Data Analysis Center |
| EROS | Earth Resources Observations System |
| ESRI | Environmental Systems Research Institute |
| FAA | Federal Aviation Administration |
| FEMA | Federal Emergency Management Agency |
| FHWA | Federal Highway Administration |
| FIRM | Flood Insurance Rate Maps |
| FY | Fiscal Year |
| GASB-34 | Governmental Accounting Standards Board No. 34 |
| GIS | Geographic Information System |
| GIS-T | Geographic Information Systems for Transportation |
| GPR | Ground Penetrating Radar |
| GPS | Global Positioning System |
| GRIP | Geographical Resource Intranet Portal |
| IFSAR | Interferometric Synthetic Aperture Radar |
| IMS | Internet Map Server |
| IMU | Inertial Measurement Unit |
| INS | Inertial Navigation System |
| IRC | Inter-Regional Corridor |
| ISU | Iowa State University |
| IT | Information Technology |

| | |
|---|---|
| I-Teams | Implementation Teams |
| ITS | Intelligent Transportation System |
| JPL | Jet Propulsion Laboratory |
| LIDAR | Light Detection and Ranging |
| LRS | Linear Referencing System |
| MN/DOT | Minnesota Department of Transportation |
| MOU | Memorandum of Understanding |
| MPO | Metropolitan Planning Organization |
| MSU | Mississippi State University |
| NAFTA | North American Foreign Trade Association |
| NAPP | National Aerial Photography Program |
| NASA | National Aeronautics and Space Administration |
| NCDOT | North Carolina Department of Transportation |
| NCFMP | North Carolina Floodplain Mapping Program |
| NCRST | National Consortium on Remote Sensing in Transportation |
| NCRST-E | National Consortium on Remote Sensing in Transportation–Environment |
| NCRST-F | National Consortium on Remote Sensing in Transportation–Flows |
| NCRST-H | National Consortium on Remote Sensing in Transportation–Hazards |
| NCRST-I | National Consortium on Remote Sensing in Transportation–Infrastructure |
| NEPA | National Environmental Policy Act |
| NGS | National Geodetic Survey |
| NOAA | National Oceanographic and Atmospheric Administration |
| NSDI | National Spatial Data Infrastructure |
| NWS | National Weather Service |
| OD | Origin–Destination |
| OREMS | Oak Ridge Evacuation Model System |
| ORNL | Oak Ridge National Laboratory |
| PC | Personal Computer |
| PCA | Principal Component Analysis |
| PENNDOT | Pennsylvania Department of Transportation |
| PLSS | Public Land Survey System |
| R&D | Research and Development |
| RFP | Request for Proposals |
| RGB | Red, Green, Blue |
| RMP | Resource Management Plan |
| RMS | Root-Mean-Square |
| RMSE | Root-Mean-Square-Error |
| RSI | Remote Sensing Industry |
| RSPA | Research and Special Programs Administration |
| RS-T | Remote Sensing for Transportation |
| RTK | Real-Time Kinematic |
| SAR | Synthetic Aperture Radar |
| SGID | State Geographic Information Database |
| SHRP | Strategic Highway Research Program |
| SPI | Space Policy Institute |
| SPOT | Satellite Probatoire d'Observation de la Terre |
| SSK | Stereo Soft Kit |
| STORM | Science Center for Teaching, Outreach, and Research in Meteorology |
| SUE | Subsurface Utility Engineering |
| TAP | Technical Application Project |
| TBD | To Be Determined |
| TEA21 | Transportation Equity Act for the 21st Century |
| TIFF | Tagged Image File Format |
| TIG | Technology Implementation Group |
| TIGER | Topologically Integrated Geographic Encoding and Referencing |
| TIP | Transportation Improvement Program |
| TRB | Transportation Research Board |
| TSC | Technology Service Corporation |
| USDOT | U.S. Department of Transportation |
| UAV | Uninhabited Aerial Vehicle |
| UBIT | Under-Bridge Inspection Truck |
| UNI | University of Northern Iowa |
| USGS | United States Geological Survey |
| VDOT | Virginia Department of Transportation |
| VMT | Vehicle Miles Traveled |
| WSDOT | Washington State Department of Transportation |

APPENDIX E

# Conference Participants

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John Albasini, *Veridian Systems Division, Stennis Space Center, Mississippi*
Fred Anderson, *Federal Aviation Administration, Oklahoma City*
William P. Anderson, *Boston University, Massachusetts*
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