# Remote Sensing for Transportation

Report of a Conference

December 4–5, 2000
**Washington, D.C.**

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THE NATIONAL ACADEMIES

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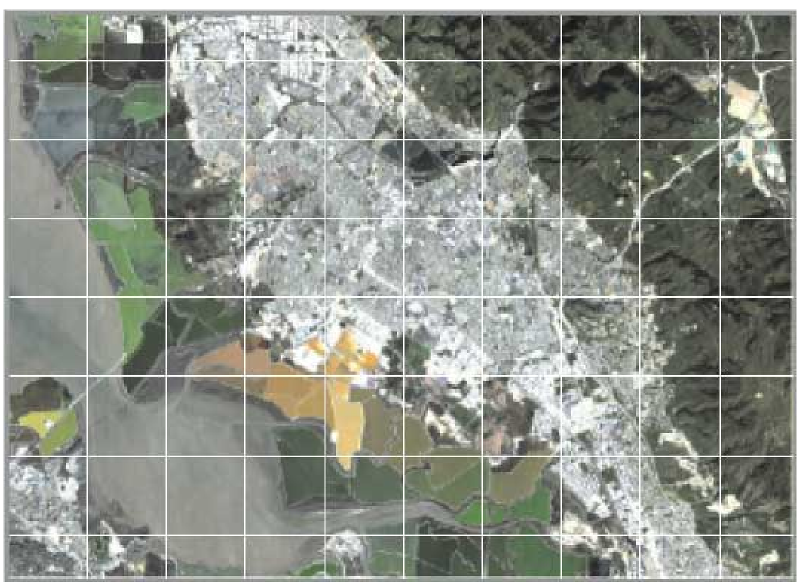
# Remote Sensing for Transportation

**REPORT OF A CONFERENCE**
**December 4–5, 2000**
**Washington, D.C.**

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

*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**
**National Research Council**
**Washington, D.C.**
**2001**

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The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

The **Transportation Research Board** is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation by stimulating and conducting research, facilitating the dissemination of information, and encouraging the implementation of research results. The Board's varied activities annually engage more than 4,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

# Foreword

These proceedings summarize the highlights from the Conference on Remote Sensing for Transportation. The conference was held December 4 and 5, 2000, at the National Academy of Sciences in Washington, D.C.

The 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 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 conference included general sessions providing an overview of remote sensing, trends in transportation, the federal research program in the use of aerial and satellite remote sensing for transportation infrastructure and development, and the activities of the four university consortia established through the federal program. Participants also discussed issues and possible research needs related to the themes of the four consortia—Traffic Surveillance, Monitoring, and Management; Environmental Assessment, Integration, and Streamlining; Transportation Infrastructure Management; and Disaster Assessment, Safety, and Hazards—in breakout sessions.

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 the time and effort they put into organizing the conference and guiding the preparation of this report. K. Thirumalai, from the Research and Special Programs Administration at the U.S. Department of Transportation, deserves special recognition for helping develop the concept for the conference and obtaining federal support for the workshop and the conference. Tom Palmerlee and Gordy Franke from the Transportation Research Board did an outstanding job with the logistics for the conference. Finally, I would like to thank all of the participants for sharing their ideas, issues, and visions related to remote sensing applications in transportation.

The goals of this conference are to improve the understanding of remote sensing among transportation professionals and key transportation issues among remote-sensing experts and to help facilitate the ongoing communication among all groups interested in remote sensing and 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 members of the conference committee responsible for the report were chosen for their special competencies and with regard for 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: Jay B. Adams, Oklahoma Department of Transportation; Robert J. Czerniak, New Mexico State University; and A. Keith Turner, Colorado School of Mines.

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. The views expressed in the presentations, papers, and discussion summaries contained in this report 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 sponsors of the conference. Responsibility for the final content of these proceedings rests entirely with the conference committee and the institution.

David S. Ekern<br>Conference Committee Chair

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# Conference Overview

**KATHERINE F. TURNBULL**
*Texas Transportation Institute*

**DAVID S. EKERN**
*Minnesota Department of Transportation*

The Conference on Remote Sensing and Spatial Information Technology for Transportation was held at the National Academy of Sciences in Washington, D.C., December 4 and 5, 2000. The conference was organized by the Transportation Research Board under the sponsorship of the Research and Special Programs Administration (RSPA) of the U.S. Department of Transportation and the National Aeronautics and Space Administration. AASHTO and the National States Geographic Information Council were cosponsors.

The conference focused on the application of remote-sensing products and services to transportation. The Transportation Equity Act for the 21st Century included funding for a multiyear research program in the use of aerial and satellite remote sensing for transportation infrastructure and development. The Commercial Remote-Sensing Application to Transportation Program, managed by RSPA, responds to the demands from the transportation community for timely spatial data, recent developments in remote-sensing technologies and capabilities, and the commercial availability of remote-sensing products and services, including high-resolution satellite imagery. The program supports research projects and technology transfer activities at four university consortia and a series of related technology application projects.

The goals of the conference were to improve the understanding of remote sensing among transportation professionals and of key transportation issues among remote-sensing experts and to help facilitate the ongoing communication among all the groups interested in remote sensing and transportation. These goals were accomplished through a combination of general sessions and breakout discussion groups. An optional workshop on remote sensing and transportation was held before the conference on December 3, 2000, at George Washington University. The conference opening sessions on December 4 provided background information on the federal programs, activities under way at the university consortia, trends in transportation, evolving responsibilities of state transportation agencies, and recent developments in remote-sensing technologies and applications.

Participants spent the afternoon in breakout groups discussing key issues and research needs. The breakout groups were organized around the themes of the university consortia: Traffic Surveillance, Monitoring, and Management; Environmental Assessment, Integration, and Streamlining; Transportation Infrastructure Management; and Disaster Assessment, Safety, and Hazards. The conference concluded on the morning of December 5 with summaries of the breakout session discussions and comments on future directions.

A number of common elements emerged from the presentations, breakout sessions, and discussions at the conference. Eight general themes capture these major elements. As highlighted next, these themes focus on closing the knowledge gap, enhancing ongoing communication, expanding workforce development and training, enhancing technology transfer, developing standards, encouraging innovative partnerships, defining specific research needs, and promoting innovative thinking. Although these eight themes do not reflect all of the items discussed at the conference, they encompass most of the critical elements raised by participants.

## CLOSING THE KNOWLEDGE GAP

Closing the knowledge gap between the remote-sensing and the transportation communities should be a top priority. Remote-sensing experts need a better understanding of the roles and responsibilities of public transportation agencies and critical transportation issues. This understanding is critical to ensure that remote-sensing applications focus on critical transportation issues and are not just technologies in search of problems. However, transportation professionals need to become more knowledgeable about available remote-sensing products and services as well as possible applications in transportation. Suggestions for helping to bridge the knowledge gap included developing a synthesis on remote sensing in transportation; encouraging regular meetings among representatives from the university consortia, product partnerships, transportation agencies, and other groups; initiating staff exchange programs; and scheduling regular conferences and workshops.

## ENHANCING ONGOING COMMUNICATION

Enhancing ongoing communication among all groups interested in remote-sensing transportation applications emerged as a second major theme during the conference. Related to closing the knowledge gap, participants stressed the importance of continuing the dialog at the conference. The participants suggested a range of methods and media to improve and maintain ongoing communications. The approaches identified included regular conferences and workshops, teleconferences, newsletters, websites, web-based list services or chat groups, videos, CD-ROMs, and other techniques.

## EXPANDING WORKFORCE DEVELOPMENT AND TRAINING

The lack of enough skilled professionals and the need for more personnel with expertise in remote sensing was voiced by many participants. The fact that transportation agencies may not be able to attract or retain specialized remote-sensing personnel was also discussed. Even if transportation agencies rely primarily on remote-sensing consultants and contractors, a need still exists for staff with an understanding of remote sensing to oversee their work and to ensure the agencies are receiving the anticipated products and services. Possible approaches for enhancing workforce development and training identified included developing and holding remote-sensing workshops and training courses, interactive CD-ROM training courses, distance learning, internships, mentoring programs, and additional support for university students and faculty in remote sensing.

## ENHANCING TECHNOLOGY TRANSFER

The need to move research findings and products quickly into practice was suggested by numerous speakers and participants. Showcasing successful transportation remote-sensing applications was noted as important. Providing research results in ways that can be used immediately by transportation agencies, such as model specifications or draft requests for proposals for certain types of services or products, was also identified as important. Ensuring that applications, especially those in the environmental area, meet the relevant requirements of regulatory agencies was noted as critical for widespread use by transportation agencies. Suggestions for improving the technology transfer process included focusing on a few key useable products or services; language appropriate for the targeted audiences and markets; and webpages, newsletters, CD-ROMs, and conferences to help promote the availability, application, and benefit of research results.

## DEVELOPING STANDARDS

A range of issues related to standards was discussed throughout the conference. The discussions covered a variety of concerns and levels. At one level, the need for basic information on the availability, accuracy, and costs of remote-sensing products and services was identified as important. At another level, the need to identify the specific scale and accuracy requirements for individual applications was noted as critical. At still another level, developing standards was identified as important, so that transportation agencies can be assured that they are receiving the anticipated product or service. Given these discussions, it would be appropriate to examine the need for standards in more detail and to outline follow-up steps as appropriate.

## ENCOURAGING INNOVATIVE PARTNERSHIPS

Partnerships are critical to the successful deployment of remote sensing in transportation. Academia, public agencies, remote-sensing product and service firms, and other groups will need to be involved in these partnerships. The successful introduction of remote sensing in transportation will require innovative public-private partnerships. Many of these public-private approaches may be new to both groups. Many public agencies still primarily rely on traditional consulting and contracting procurement methods with the private sector. Remote-sensing firms may not be used to dealing with public agencies. Issues such as multiple licenses, shared use of data, and liability will all need to be explored. Approaches identified to help facilitate change included providing case study examples of successful public-private partnerships, peer-to-peer contacts, and examination of the approaches used in other industries.

## DEFINING SPECIFIC RESEARCH NEEDS

A number of specific research topics were identified during the breakout sessions and other discussions. Cost-benefit studies on specific remote-sensing applications were one of the most frequently cited research needs. Other suggestions focused on specific applications. The following examples highlight the research needs suggested. The breakout group summaries provide more specific suggestions under each of the four themes.

- Assessing the cost-benefit of remote-sensing transportation applications.
- Developing metrics and measuring tools.
- Using remote sensing for transportation modes other than highways and roadways.
- Using remote sensing for regional studies.
- Developing and maintaining databases for specific infrastructure elements.
- Measuring and monitoring trip and travel time reliability.

- Measuring and monitoring soils, wetlands, water quality, floodplains, cultural resources, habitats, and other environmental factors.

## PROMOTING INNOVATIVE THINKING

Recognizing that changes in the public sector usually occur slowly, the introduction of remote sensing in transportation will not occur overnight. Instead, the application of remote sensing in transportation will likely occur in small steps. Even with this realization, participants voiced the need for individuals in both the public and the private sectors to be creative and innovative in applying remote sensing to critical transportation problems. Nontraditional thinking and new and different approaches were suggested as important for advancing remote sensing in transportation.

These conference proceedings may be used by numerous groups to assist in defining critical research, technology transfer, and workforce training needs and to help advance the deployment of remote-sensing products and services in transportation. First, the conference results have value to RSPA and to the university consortia by defining future program elements, activities, and specific projects. Second, product demonstration partners and other remote-sensing firms may use the proceedings to identify applications, products, and services needed by the transportation community. Third, ideas on research synthesis topics and research projects may be considered through NCHRP, the Transit Cooperative Research Program, and others. Finally, these proceedings help to start bridging the knowledge gap between the transportation and remote-sensing communities and encourage ongoing communication among all the interested groups.

# Welcome

**DAVID S. EKERN**
*Minnesota Department of Transportation*
*Conference Committee Chair*

It is a pleasure to welcome you to the Conference on Remote Sensing for Transportation. This conference represents the first step in developing an ongoing dialog to advance the application of remote-sensing technologies to address critical transportation issues. I would like to recognize and thank the members of the Steering Committee for their hard work in organizing the conference. K. Thirumalai of the Research and Special Projects Administration (RSPA) deserves special recognition for his efforts in guiding the development of the entire transportation remote-sensing program and his help with this conference.

This conference was organized by the Transportation Research Board, AASHTO, and the National States Geographic Information Council to foster interaction among universities, remote-sensing firms, and the transportation community. I want to thank RSPA and the National Aeronautical Space Administration for providing funding for the conference.

Transportation agencies at all levels are facing unprecedented pressures to fulfill new missions and to take on additional responsibilities. At the same time, we are challenged to preserve the existing transportation system, to better understand customer desires, to retool our workforce and service provision models, and to develop new partnerships with other public agencies and private businesses.

New technologies and tools are available to the transportation community to help meet these challenges. Remote-sensing technologies represent one of these new tools. Remote sensing is more than just aerial photography. Realizing the full benefits from these technologies will require professionals with new skills and abilities. I would liken the changes we will see over the next few years to those experienced by many state departments of transportation (DOTs) in the late 1970s and early 1980s when we changed from paper and ink to computer-aided design for designing roadways and freeways.

Aerial and satellite remote sensing is experiencing rapid changes in technologies, techniques, and capabilities. The U.S. Department of Transportation (DOT) initiated a multimillion dollar research program in the use of aerial and satellite remote sensing for transportation infrastructure and development. The program includes four university consortia and a series of related technology application projects in remote sensing. A new solicitation for project applications has just been issued by RSPA and is included in your conference materials.

The efforts sponsored by U.S. DOT represent only some of the interest in using remote-sensing and spatial information technologies with transportation. The Minnesota Department of Transportation (MnDOT) is on the threshold of implementing a variety of tools for collecting and using geospatial information in numerous applications.

At the AASHTO meeting in Indianapolis next week, the Board of Directors will be considering formal action related to spatial information needs. A proposal to establish a special subcommittee to address these issues will be considered. A new AASHTO committee, called the

Technology Deployment Steering Group, will meet for the first time to consider processes and approaches state DOTs can use to facilitate the deployment of relevant technologies.

Part of my job as an assistant commissioner at MnDOT is to help the state participate in a wide variety of national initiatives that foster the advancement of new technologies, techniques, and processes. We realize that one agency and one state can accomplish more by working with other states and groups than by working alone. Partnerships are needed among public agencies and between the public and the private sectors to help meet the transportation challenges we face today.

This conference provides an excellent opportunity to better understand the capabilities remote sensing can offer for transportation, to comment on the scope and relevance of the initial funded research projects, and to identify the priorities for future work. These elements represent the key objectives of the conference.

The goals of this conference are to improve the understanding of remote sensing among transportation professionals and key transportation issues among remote-sensing experts and to help facilitate the ongoing communication among all the groups interested in remote sensing and transportation. I urge you to become actively engaged over the next 2 days, both in formal and informal discussions. The generation of ideas, potential research projects, technology transfer activities, and training efforts are key outcomes of the conference.

The workshop Sunday afternoon, which was attended by approximately 80 people, provided a great start to this dialog. Presentations focused on sensing and spatial information technologies, capabilities, and transportation applications. The exchange of ideas among participants started at the workshop.

We have about 150 individuals here today to continue the work started yesterday. State DOTs, private businesses, universities, and regional and local governments are all represented. The full range of groups needed to advance the use of remote-sensing technologies to address critical transportation issues is here.

It is important to remember that this conference is not a one-time event. Rather, it represents the beginning of an ongoing dialog. The U.S. DOT program is a multiyear initiative. The university consortia are in the first year of a multiyear program. Only the first round of technology application projects has been awarded. The conference represents the opportunity to help shape future research projects and activities. A second conference will be held December 10–12, 2001, here in Washington, D.C., to help ensure that the dialog continues.

The conference is divided into three parts. The sessions this morning will provide a general orientation to remote sensing, the efforts under way at RSPA, factors influencing changes at state DOTs, and research projects under way at the various universities.

This afternoon will be spent in breakout sessions organized around the four themes of the university consortia. These themes are Traffic Surveillance, Monitoring, and Management; Environmental Assessment, Integration, and Streamlining; Transportation Infrastructure Management; and Hazards, Safety, and Disaster Assessment. Participants will be asked to comment on current consortia programs, to identify potential projects that meet critical transportation needs, and to discuss potential barriers to implementation and actions that will help advance the use of remote sensing in transportation.

Tomorrow morning the key items discussed in the breakout groups will be presented. The conference will conclude with a panel discussion. You will have the opportunity to add any final comments at the closing session.

I would like to thank you all again for participating in this important conference. I look forward to productive discussions over the next 2 days.

# Transportation Vision for 2050

**EDWARD BRIGHAM**
*Federal Highway Administration*

Thank you, Dave, for that gracious introduction. The Transportation Research Board is very fortunate to have your leadership for this conference bringing transportation practitioners and remote-sensing technologists together. The U.S. Department of Transportation (DOT) hopes the conference will help accelerate the application of remote-sensing innovations to transportation practice.

Deputy Secretary Downey conveys his regrets for not being able to be here today. On his behalf and on behalf of Research and Special Projects Administration (RSPA) Administrator Coyner, I would like to give you a status report on the remote-sensing program at RSPA and to help set the stage for further discussions at the conference.

Secretary Slater and Deputy Secretary Downey have been diligent leaders striving for a "visionary and vigilant" U.S. DOT and pointing the way to transportation excellence in the 21st century. They have helped to energize the flow of innovations and enabling technologies to transportation systems. Together, they redefined transportation beyond a narrow public works definition, fostered technological innovations in transportation systems, and utilized public-private partnerships to achieve transportation goals. The remote-sensing program is an excellent example of a successful collaborative partnership bringing innovations to 21st Century transportation practice.

The program was authorized under Section 5113 of the Transportation Equity Act for the 21st Century. The program's objective is to validate commercial remote-sensing products and spatial information technologies for application to national transportation infrastructure development and construction. A year ago, U.S. DOT and the National Aeronautics and Space Administration (NASA) signed a Memorandum of Understanding to implement the program.

The program combines NASA research experience in remote-sensing technologies with U.S. DOT's expertise in technology assessment and experience in transferring research results into transportation practice. This partnership provides a winning combination for applying remote-sensing innovations to transportation practice. Remote sensing also is a ONE DOT program, with all modal administrations in U.S. DOT working together. RSPA manages the program with the assistance of experts assigned from each modal administration.

Teams comprised of staff from NASA and U.S. DOT worked together to develop a program that serves both NASA's interest in technology application and U.S. DOT's interest in improving transportation practice. We jointly convened program stakeholders including federal agencies, academia, industries, service providers, and researchers in a series of national meetings. A consensus was achieved at these meetings on four technology application areas with expected high payoffs.

These four technology application areas are Traffic Surveillance, Monitoring, and Management to improve traffic flow; Environmental Assessment, Integration, and Streamlining; Transportation Infrastructure Management; and Hazards, Safety, and Disaster Assessment. These four topic areas are reflected in the university consortia themes.

U.S. DOT developed a balanced program to implement these consensus recommendations. The program focuses on advancing near-term product applications, long-term research, and workforce development. We used an innovative and flexible procurement tool known as “other transactions” to solicit, negotiate, and award projects expeditiously with performance-based objectives. Public-private partnerships are the fundamental base for all awards made under the remote-sensing program. These partnerships share the technical expertise, resources, risks, and results of applying remote-sensing technology to transportation practice and bringing innovations to the transportation marketplace.

The product demonstrations are being implemented by service providers and industries. These projects select commercially available remote-sensing products and demonstrate their potential to meet high-priority transportation needs. The results will provide guidelines for real-world applications. We awarded several product demonstration projects in the first year. We hope to build on these results and award additional demonstration projects in Fiscal Year (FY) 2001. A Broad Agency Announcement for the FY 2001 round of awards has just been released and copies are available at the conference registration desk.

The long-term research is being performed by the university consortia. The consortia are designed to expand the remote-sensing technology base, to identify new innovations for transportation applications, and to train the workforce necessary to apply those innovations. Four university consortia have been established, which will continue for the full life of the program. Each consortium emphasizes one of the four priority technology areas for transportation application. It is our intent that these centers become world-class research leaders for remote-sensing applications in transportation.

We believe the collaborative public-private partnership model developed and implemented by U.S. DOT in this program is very effective and maximizes the opportunity for successful applications of new and emerging technologies to transportation practice. The model provides an excellent structure for other programs fostering innovation in the future. Thirumalai from RSPA will present more details about the results and products emerging from the program later in this session.

Quite simply, our objective for this conference is to raise the level of understanding about commercial remote-sensing tools, technologies, and processes. The next 2 days will provide opportunities for one-on-one dialogue between product developers and product users in the transportation field. We hope these interactions will result in the application of commercial remote-sensing technologies to unique solutions for important transportation issues. We expect the results of the remote-sensing program will lead to safer, cheaper, faster, and more efficient transportation in the 21st Century for our nation’s citizens.

Let me close by wishing you a successful conference.

# Remote Sensing for 2050

**MICHAEL THOMAS**
*National Aeronautics and Space Administration*

It is a pleasure to have the opportunity to participate in this important conference. You are all aware of the National Aeronautics and Space Administration's (NASA) work in space exploration. You may not know that NASA is also very interested in earth science and has major research efforts focusing on how the Earth works as a planet.

It is a challenge for NASA to coordinate and work with other governmental agencies with operating responsibilities. NASA is a research and development agency; our roles and responsibilities are much different from those of the U.S. Department of Transportation (DOT) and other agencies. NASA's interest in Earth systems is in long-term basic research. It is a departure for NASA to work with U.S. DOT and other agencies on short-term applied research and technology transfer.

There are five basic questions that NASA's Earth Science Enterprise focuses on. These questions are

- How is the Earth system changing?
- What are the primary forcing factors on the Earth's system?
- How does the Earth system respond to natural and human-induced changes?
- What are the consequences of change for our civilization?
- How well can we predict future changes in the Earth's system?

These questions are global in scope. In studying these questions, NASA learned a great deal and developed expertise in numerous areas. We hope to bring this experience and expertise to our partnership with U.S. DOT.

As highlighted in Figure 1, NASA has a 40-year history of observing the Earth, beginning in the 1960s with the TIROS Weather Satellite. Most people are familiar with the Landsat work


**FIGURE 1**

during the 1970s. More recent efforts included the Earth Radiation Bulge in the 1980s and the Upper Atmosphere research in the 1990s.

Figures 2 through 5 illustrate recent images from NASA satellites and the space shuttle. They include a Saharan dust storm, Hurricane Floyd off the coast of North Carolina, Oahu and the St. Pierce and Miquelon Islands, and the Nile River delta.

The Saharan Desert image provides one example of how satellite data can be used in earth science studies. Dust blows all the way from the Saharan to the Caribbean. Bacteria and other microbes are carried along with the dust particles. This movement can be traced by satellite imagery. We are just beginning to understand the influence of these factors on the environment.

Observing the influence of different forces on climate is a major focus of current efforts. A series of satellites are being used to examine a variety of climatic factors as well as changes to the oceans, atmosphere, and land surface.

NASA envisions an Earth observation system by 2050. As highlighted in Figure 6, this system would include satellites, uninhabited air vehicles, and other airborne remote-sensing technologies. The important element of the system, however, would be networking all the information together. We are a little behind the U.S. Department of Defense on information fusion, but we are catching up. Communications, sensor fusion, and other related technologies will be important elements in the system. Understanding the user community is also a critical part of the system. We really need your help to understand transportation issues and to

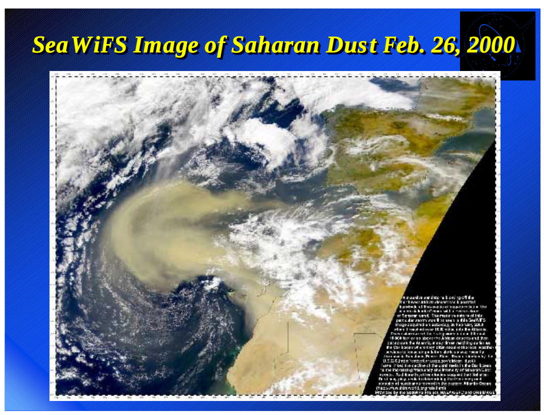


**FIGURE 2**

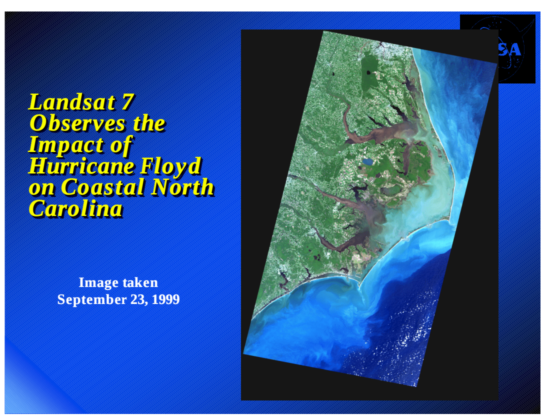


**FIGURE 3**


**FIGURE 4**

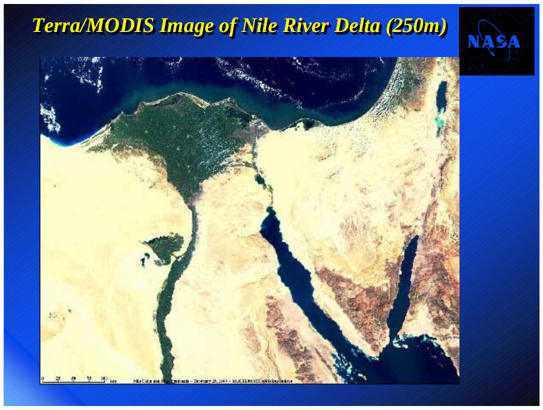


**FIGURE 5**

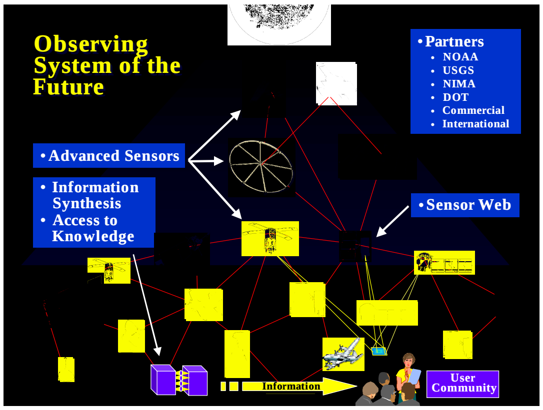


**FIGURE 6**

identify how NASA's investment in science and technology can be of benefit in addressing these problems.

NASA is also very interested in education and workforce development. NASA is participating with the American Society of Photogrammy and Remote Sensing in a 10-year industry forecast. Interviews are being conducted with chief executive officers of many geographic information system (GIS) and remote-sensing companies as part of this study. An emerging theme from these interviews is that workforce development is a huge barrier to the growth of the remote-sensing industry. There simply are not enough trained professionals in the workforce with an understanding of remote sensing, remote-sensing imagery, and GIS as well as an understanding of how to apply these technologies to practical problems. Funding is being devoted this year to workforce development activities.

In addition to the Broad Agency Announcement (BAA) mentioned by previous speakers, NASA also has a second BAA out. This BAA is called the State, Local, and Tribal Government Initiative. This initiative is similar to the U.S. DOT BAA. We intend to develop a flexible solicitation that will stay open for a year. It will be easy to propose under this solicitation. We are looking for a full range of projects related to the environment, community growth, infrastructure, transportation, disaster management, and resource management.

NASA is committed to providing a different view of the Earth. This view will have more practical benefits to taxpayers in terms of transportation, service management, the environment, and disaster management. With your help, we hope that we can achieve this vision. I look forward to talking with you during the conference and working with you in the future.

# The Changing Face of Departments of Transportation

**ROBERT E. SKINNER, JR.**
*Transportation Research Board*

It is a pleasure to welcome you to this conference. I would like to thank the Research and Special Projects Administration and the National Aeronautics and Space Administration for providing support to help make this conference possible. My task this morning is to describe the changing face of state departments of transportation (DOTs). I will first highlight the environment within which transportation agencies operate today and then describe how transportation agencies are changing as a result of those environmental factors. I will close by discussing the opportunities and challenges for innovation in the public transportation sector.

Numerous demographic changes continue to occur in the United States. A 20 percent increase in population is projected by 2020, with a 43 percent increase in 2050. One million people are added each year through immigration alone. Thus, the nation's population is changing in terms of both numbers and background. We are also an aging population. This segment of the population will want to maintain their lifestyles, and transportation will continue to play a key role in providing mobility and accessibility.

Women have nearly closed the gap with men on workforce participation. Women's rate of participation in the workforce is about 80 percent of that of men. Women's rates for having a driver's license are approximately 92 percent of men's rates. With almost everyone working, trip and travel patterns are very complex. Trip chaining is the norm today. Work trips are frequently combined with shopping, child care needs, and other activities.

We are a much more affluent country than we used to be. In constant dollars, our income in 1998 was one-third higher than it was in 1980. Affluence is positively correlated with travel and travel demand, especially for leisure trips. We have become a heavily suburbanized nation. Nearly 50 percent of the country's population lives in the suburbs. Suburban-to-suburban work trips, which accounted for only 15 percent of all work trips in 1970, now comprise 44 percent. I think that when the results of the 2000 Census are available, this percentage will be even higher. The suburbs have become a place to both live and work.

The nation has also become saturated with motor vehicles. We have almost one vehicle for every man, woman, and child. Over 90 percent of all work trips are made by automobile and 80 percent of intercity trips over 100 mi are made by motor vehicle. Trucks account for 24 percent of freight ton miles and 72 percent of all freight movement by value.

The transportation infrastructure has not kept pace with this growth in population and travel demand. Between 1980 and 1997, lane miles increased by 4 percent, while motor vehicles increased by 31 percent and vehicle miles of travel grew by 67 percent. Traffic congestion is of course the result of these trends.

We all experience some level of traffic congestion on a daily basis. The Texas Transportation Institute analyzes congestion levels in major metropolitan areas throughout the country and publishes an annual status report. The results of this ongoing study are widely publicized in cities throughout the country.

Congestion affects other modes as well as highways and roadways. Waterways and port facilities are experiencing problems resulting from aging equipment and mismatches with technology as container ship, deep draft ship, and double-stacked railcars are all used more. Container traffic at the Los Angeles and Long Beach (both in California) ports has doubled over the last decade.

Railroad capital spending is no longer keeping pace with both the depreciation and retirement of aging equipment. Average speeds on the rail network have declined since 1992. You are familiar with the problems associated with the aviation industry. Only one major new airport has been constructed in the past 25 years. The air traffic control system is still struggling to introduce late-20th Century technology.

What does the American public expect for the future? I would suggest that the public's expectations are incredibly high. Americans want it all. We want more mobility, more accessibility, more personal space; we want a high-quality, sustainable environment. In the future, there will be more of us wanting all of these things. Meeting these expectations will be a tremendous challenge.

As you know, the transportation industry is not a single industry. Rather, it is a collection of industries—a public and private enterprise that is incredibly decentralized. There are over 30,000 public agencies in the United States that own and operate highways. There are some 6,000 agencies that operate public transit systems. There are tens of thousands of material and service suppliers that are used by transportation agencies. There are also tens of thousands of private concerns, such as trucking companies, that use roadways and freeways for commercial purposes.

The last 20 years have seen a dramatic period of change in the private sector. There have been consolidations in railroads and airlines and more recently in the construction, design, and engineering fields. There has been downsizing and streamlining. For example, the number of railroad track miles in the country has declined by 30 percent over the past 20 years. During the 12-year period from 1985 to 1997, the Class I railroads shed over one-third of their workforces but increased the ton miles carried by 50 percent. The size of the railroad system and the number of employees both declined, but the volume of traffic increased significantly.

We have reengineered the supply chain. Just-in-time delivery is now the norm. Transportation has become part of the manufacturing process. Highways are now the warehouses of the manufacturing process. While these trends have been going on, there has been an improvement in service and productivity in the private sector. We have seen tremendous consumer benefits in terms of systemwide measures like service frequency and price. A combination of deregulation, introduction of information technology, and globalization seems to be responsible for these productivity gains. These elements have forced changes in the private sector as well.

Organizational change in the public sector has been much more modest, largely because public transportation agencies cannot act unilaterally or with the agility and swiftness seen in the private sector. There have been changes in the public sector over the past 20 years, however. State DOTs have changed over this time period to provide better services, to reduce costs, and to address new constraints.

State DOTs are smaller than they used to be. All but a dozen state agencies have fewer employees today than in the past. At the same time, state DOTs are taking on new roles and responsibilities. Most agencies are facing greater demands and responsibilities with fewer employees. Although state DOTs are smaller today, their workforce is much more diverse than it was in the past. I am told that state DOTs employ the most archeologists of any public- or private-sector organization in the country.

State transportation agencies are using the private sector much more than in the past. There has been an increase in outsourcing of design and engineering services. We are beginning to see the outsourcing of routine maintenance services. These trends are likely to continue, with more use of private firms for all types of services.

State transportation departments are also introducing procurement reforms. Traditionally, these agencies have used traditional method specifications, which provide specific guidance on what to build and how to build it. Many agencies are moving toward greater use of performance specifications. They are also exploring procurement methods that share risk with the private sector through warrantees, design-build, and other approaches.

Many state DOTs have redefined their missions. This change is fulfilling the promise of the 1970s, when many changed from highway agencies to state DOTs. Many are becoming truly multimodal organizations that focus on more than just the highway system to solve transportation problems.

State transportation agencies are becoming more customer driven. Most states do some type of survey of users to help identify priorities and expectations. Pavement smoothness, safety, and congestion seem to be the top three issues of concern. Although state agencies have made a number of significant changes recently, there is still much to be done.

There has never been a greater need for innovation in the transportation field than there is right now. Remote-sensing technologies are one of a large group of advanced technologies that can potentially help state transportation agencies respond to the challenges outlined previously. In essence, transportation agencies are being asked to take on more responsibilities with fewer staff, to provide more services, and to operate within fiscal constraints that are present regardless of how good (or bad) the economy is.

We are moving from a period of constructing new facilities to one of operating the existing system more efficiently. At the same time, Americans are concerned about more than just mobility and accessibility. We are also concerned about the impacts of transportation facilities on the environment and society. State transportation agencies face significant challenges in meeting these expectations.

There are formidable barriers to innovation in the public sector. First and foremost is the decentralization mentioned earlier. Introducing innovation in the multitude of public agencies responsible for different parts of the transportation system is not easy. There are also relatively few incentives to introduce innovations in the public sector. Even with recent changes, most transportation agencies still rely on prescriptive procurement specifications, usually focusing on the lowest bidder. There are no incentives for a contractor to deliver a 20 percent better product at only 2 percent added cost. This mentality is especially troublesome for the introduction of new and evolving technologies. The prescriptive method specifications approach cannot accommodate new methods and techniques.

The potential upside gain from doing something different in the public sector is often out weighed by the possible downside risk. If something is done wrong, it may cause major problems for both the staff and agency; whereas if it goes right, it may not even be newsworthy.

Finally, state transportation agencies and other public transportation organizations have low-tech images. The public tends to think that these agencies are doing things the way they have always been done. Whereas this perception is wrong in many cases, it still must be overcome as new technologies, methods, and techniques are introduced at transportation agencies.

In conclusion, transportation agencies will continue to be challenged to accommodate increasing demands and to respond in environmentally and socially sensitive ways. In my view, innovation will be essential to help meet those challenges. Introducing innovations in a less than hospitable climate is not easy. State transportation agencies have started the change process, and remote-sensing technologies can play an important part in helping public transportation agencies take on new roles and responsibilities.

The introduction of remote-sensing techniques within state DOTs is important for a number of reasons. First, it will help these agencies meet their growing responsibilities in a cost-effective way. Second, improvements from the use of remote-sensing technologies will be passed on to the traveling public and commercial users. Third, state DOTs can foster more widespread applications through their partnerships with local, regional, and federal agencies.

Thank you for your attentiveness. It is a pleasure to speak with you this morning. I wish you well with your conference over the next 2 days.

# U.S. Department of Transportation Remote-Sensing Program and Other Agency Programs

**K. THIRUMALAI**
*U.S. Department of Transportation*

It is pleasure to welcome you to this conference. Bob Skinner did an excellent job describing the changing scene in transportation practice. He also made an excellent point that we need to look and think differently in providing transportation services to meet future demands. He also emphasized the importance of innovation and applying new technologies to transportation problems. This conference focuses on those topics, namely, trying to match innovation and advanced technologies to provide transportation services cheaper, faster, and better.

When we look at the immensity of the transportation infrastructure and its importance to everyday life, it is apparent that even a small improvement in providing transportation services could result in large savings in transportation costs. For example, it is conceivable that commercial remote-sensing technologies could be applied to monitor damage to the transportation infrastructure from national disasters and to improve our ability to respond appropriately. Bringing examples like this one into practice would result in significant savings and benefits.

The U.S. Department of Transportation (DOT) organized the Commercial Remote-Sensing Application to Transportation Program around three major goals. The first goal focuses on demonstrating potential remote-sensing applications for achieving a "better, cheaper, and smarter" transportation system for the 21st Century. Establishing and maintaining partnerships with academia, service providers, industries, and users to conduct research and to move applications into practice is the second goal of the program. Professional workforce development represents the third program goal.

U.S. DOT uses proven methods and innovative approaches to accomplish these goals. Program elements focus on education and training, enabling research, and product development partnerships. Support and partnerships with state, regional, and local agencies and transportation users are critical for transferring remote-sensing technology applications into practice.

The program was developed with extensive stakeholder participation. Forums were held with representatives from state, regional, and local transportation agencies; universities and research organizations; and industry groups. A consensus emerged from these forums on the high payoff areas for applying remote-sensing products and services to transportation.

Four priority areas emerged from the forums. These topic areas were congestion mitigation and traffic flow; environmental impact assessment; management of the physical infrastructure; and assessment of risks, hazards, and disasters. The themes for the four university consortia have been organized around these topics.

The program has two integrated tracks. The first track focuses on near-term product demonstrations in partnership with remote-sensing service providers. These projects will demonstrate the application of commercial remote-sensing products and services to transportation. The second track focuses on fostering long-term, knowledge-based developments through the university consortia. These efforts will help advance innovative technology applications and promote workforce development.

U.S. DOT further identified four key features for the near-term product demonstrations. First, the product demonstrations should address a priority topic area. Second, they should provide the opportunity for near-term implementation. Third, demonstrations are intended to promote low-cost product applications. Finally, the product demonstration should have the potential for high pay-offs.

The university consortia program complements the product development projects but takes a longer-term look at research needs and workforce development. The university consortia program serves as an intellectual driver for innovations in remote-sensing technology and promotes world-class technical excellence. It also provides a one-stop center for technical assistance to state, regional, and local agencies. The final key component of the university consortia is professional capacity building and transportation workforce development.

I would like to briefly highlight the activities under way in the four topic areas. As David Ekern mentioned, the breakout sessions this afternoon are organizations around these four themes. More information on each consortium will be presented in the next sessions.

Ohio State University is leading the Traffic Surveillance, Monitoring, and Management Consortium. The University of Arizona and George Mason University are the other academic partners in this consortium. The product demonstration partners include Technology Services Corporation, Veridian Erim International, the GeoGraphics Laboratory at Bridgewater State College, and the Transportation Center at the University of Massachusetts. Research projects being conducted by the consortium focus on integrating remotely sensed traffic flow data with traditional data-collection methods to enhance the efficiency of the transportation system.

The Environmental Assessment, Integration, and Streamlining Consortium is lead by Mississippi State University. Other academic partners include the University of Alabama in Huntsville, University of Mississippi, and Auburn University. EarthWatch, Inc., and Intermap Technologies, Inc., are product demonstration partners. Research under way by this consortium focuses on the application of remote sensing to measure, monitor, and assess environmental conditions in relation to transportation infrastructure.

The University of California, Santa Barbara, is leading the Transportation Infrastructure Management Consortium. The University of Wisconsin—Madison, Iowa State University, and University of Florida are the academic partners. Tetra Tech ASL and Orbital Imaging Corporation are the product demonstration partners.

The University of New Mexico is the lead on the Disaster Assessment, Safety, and Hazards Consortium. The University of Utah, George Washington University, and Oak Ridge National Laboratory are the other partners. AERIS, Inc., and EarthWatch, Inc., are the product demonstration partners. The activities of this consortium focus on using remote sensing to enhance planning for responding to natural disasters and man-made hazards.

Each of the consortia is addressing short-term applications of remote-sensing products and services to transportation, innovative longer-term research to match remote sensing to critical transportation problems, and workforce development. The public-private partnerships established through the consortia and the product demonstrations are key elements of the program.

There is also a desire to push the envelope of remote-sensing technology applications to meet critical transportation needs in the 21st Century. The vision for the technical program in future years includes exploring new applications to transportation dynamics, near real-time imagery data management, and integrating remote sensing with surface sonar and intelligent transportation systems.

Future activities in the business program will focus on remote-sensing applications to reduce the cost of transportation services and on reaching global markets for American products and services. Possible applications of remote-sensing products and services to reduce transportation costs include regional traffic-monitoring systems, environmental assessments, infrastructure inventories and management systems, pavement and bridge condition assessments, and monitoring transportation lifeline systems.

The Commercial Remote-Sensing Application to Transportation Program is off to a good start. The efforts of many conference participants and other individuals have been instrumental in the successful initiation of the program components. The future looks bright for the program and for the application of remote-sensing products and services to help address critical transportation problems. I look forward to the discussions at the conference and working with you on future activities.

# The Changing Face of Remote Sensing

**JOHN R. JENSEN**
*University of South Carolina*

It is a pleasure to participate in the opening session of this conference. I would like to highlight a few key points from my paper, "The Changing Face of Remote Sensing," prepared specifically for this conference. (The full paper is provided in the Appendix.) I would also like to provide a historical perspective on the development and use of remote sensing.

"Remote sensing" is defined as the collection of information about an object without direct physical contact with it. The first photograph, which was taken with a wooden box camera, required 8 h to shoot. Cameras can be thought of as the first remote-sensing device. Aerial photography from balloons was used during the U.S. Civil War, but no photographs exist from this period. The first known aerial photograph in the United States was taken in 1860 from a balloon in Boston. Cameras were also strapped to pigeons in the early 1900s to provide aerial photographs.

It was not long after the Wright brothers' first flight at Kitty Hawk (N.C.) that experiments with cameras in airplanes began. Aerial photographs, remote sensing, and photo interpretation advanced rapidly during World War II. The U2 aircraft provided air reconnaissance after the war. Aerial photographs played a key role in the Cuban Missile Crisis during the early 1960s. The first images from satellite also occurred during the 1960s. The first Landsat launch occurred in 1972, and the Landsat 7 launch took place in 1999.

It is important to understand a few of the key terms used in remote sensing. These terms include spectral resolution, spatial resolution, temporal resolution, and radiometric resolution. "Spectral resolution" refers to the number and dimension of specific wavelength intervals in the electromagnetic spectrum to which a remote-sensing instrument is sensitive. "Spatial resolution" is the measure of the smallest angular or linear separation between two objects that can be resolved by the sensor (also referred to as "ground resolve distance"). "Temporal resolution" refers to how often a remote-sensing system records imagery of a particular geographic area. "Radiometric resolution" is defined as the sensitivity of a remote-sensing detector to differences in signal strength as it records the radiant flux reflected or emitted from the terrain.

The spatial resolution should be matched to the problem or issue examined and with the spectral resolution needed to disseminate a type of contrast among the various features. The problem should be matched to the appropriate data resolution needed to extract the desired information. Monitoring change over time is also critical. Everything has a phenological cycle, even urban environments.

The process for creating information from remote-sensing data is discussed in my paper. The raw data may come from satellites, airplanes, or other technologies. The raw data is processed to provide information that has use and value to specific customers. If remote-sensing applications are to become widespread in transportation, the information must have a perceived value to the user. Remote sensing must be a cost-effective way to obtain the information, and the process must be relatively easy to use. These elements can be thought of as an equilibrium. If the remote-sensing information does not have value or is too costly and too difficult to use, it will not be accepted by transportation agencies.

I would also suggest that there is a knowledge gap between the remote-sensing and the transportation communities. A great deal of remote-sensing data is currently available. This data needs to be converted into information that has use and benefit to transportation professionals. Currently, the remote-sensing community does understand the critical transportation problems well enough to be able to convert data into useful information. At the same time, transportation professionals do not have a good grasp of remote-sensing products and services and how these might be applied in transportation. This conference and the work under way at the university consortia provide a good start for bridging this knowledge gap.

The remote-sensing data-analysis process follows a similar pattern, regardless of the specific problem examined. A hypothesis is formulated first. Then the remote-sensing data and the field data are collected. The data are analyzed using analog, digital, or visual techniques. The hypothesis is tested and either accepted or rejected. The data are then made available through an analog or digital product, and the information is communicated to various customers.

Examples of urban and suburban applications of remote-sensing data are summarized in my paper. The spatial and the temporal resolutions needed for transportation applications vary by the specific problems examined. Most urban and suburban applications require very high-resolution data. The majority of government sensor systems provides relatively coarse resolution and, thus, may not meet the needs of the transportation community. The characteristics of the transportation problem or topic addressed should be matched to the appropriate remote-sensing technology, resolution, and accuracy.

There is a whole new group of sensor systems in addition to aerial photography. It is important to keep in mind the limitations of these sensors and to not oversell the capabilities of remote sensing. A number of factors contribute to a successful remote-sensing project. These elements include field work, weather, the sensor, emulsions, and the people involved. Photogrammetry still remains one of the best remote-sensing approaches. Even with other sensor technologies, photogrammetry remains the heart and soul of many remote-sensing applications. Photogrammetry also has limitations, especially related to determining relief.

Soft-copy photogrammetry has replaced orthophotogrammetry to provide three-dimensional information. This technique has numerous applications, frequently related to documenting such specific conditions as the results of earthquakes, other natural disasters, and accidents. It is also used to monitor the Strategic Arms Treaty. A number of private companies are working to develop more user-friendly packages and other applications for soft-copy photogrammetry. The results can also be incorporated into other software packages, including visualization techniques.

Digital cameras are also replacing many of the traditional film cameras. Digital cameras provide greater radiometric resolution than film does. In addition, the military is declassifying a good deal of remote-sensing data that may be appropriate for transportation applications.

Linear array “pushbrooms” represent another set of new technologies. These technologies use linear arrays of stable detectors that achieve a higher degree of geometric stability imagery. The systems can also obtain overlapping stereoscopic views and have advantages over other approaches.

Light detection and ranging (LIDAR) and information extraction methods are new techniques used in numerous applications, including transportation. LIDAR sensors measure active pulse travel time from a transmitter on an airplane to the object and back to the receiver. A series of data points, arranged across the flight line, is recorded as the aircraft flies forward. LIDAR can penetrate vegetation canopies and maps the surface below, which is more difficult to obtain with aerial photography. In one recent example, LIDAR was used for floodplain mapping in North Carolina. Although there are no current operational satellite LIDAR systems, NASA's vegetation canopy LIDAR is scheduled to be launched in 2001. This system should provide data useful for numerous urban applications, including transportation.

Landsat and other scanning systems are still widely used because they provide very useful data. These systems are especially good for regional assessments of vegetation, wetlands, forest, range land, and other related information. Higher spatial resolution and higher spectral resolution are needed for more detailed site-specific assessments. New scanner technologies, including systems encompassing neural networks, are also becoming available. New developments are also occurring in image processing.

Finally, advancements are being made in hyperspectral remote-sensing and information extraction methods. These systems provide high-resolution reflectance spectrums for each picture element in an image. Specialized techniques are needed to analyze the data provided by these hyperspectral systems.

As you can see, there are numerous remote-sensing technologies available for application in transportation. The key is to match the appropriate remote-sensing system to the specific transportation problem or issue being addressed. I look forward to the discussion at this conference related to applying remote sensing to help examine key transportation concerns.

NATIONAL CONSORTIA FOR REMOTE SENSING FOR TRANSPORTATION PRESENTATIONS

# Participating Consortia

**DAVID S. EKERN**
*Minnesota Department of Transportation*
*Session Moderator*

## DISASTER ASSESSMENT, SAFETY, AND HAZARDS

### Participants

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

### Associated Technology Application Projects

- Aeris Inc.: Airborne Ground Penetrating Radar for Detection of Subterranean Pipelines and Spills.
- EarthWatch, Inc (DigitalGlobe): Environmental Impact and Risk Modeling of Petroleum and Gas Transmission Lines Using Interferometry and High-Resolution Imagery from Satellite and Airborne-Based Remote-Sensing Systems.

## ENVIRONMENTAL ASSESSMENT

### Participants

- Mississippi State University
- University of Mississippi
- Auburn University
- Global Hydrology and Climate Center
- University of Alabama in Huntsville
- Universities Space Research Associates
- Digital Globe
- Intermap Technologies, Inc.
- EarthData Technologies, LLC
- Itres, Inc.

### Associated Technology Application Projects

- ICF Consulting: Remote Sensing of Environmental Parameters for Use Streamling the NEPA Process.
- EarthData Technologies: Airborne Sensor Fusion: A Fast-Track Approach to the NEPA Streamlining and Environmental Assessment.

## FLOWS

### Participants

- Ohio State University
- George Mason University
- University of Arizona

### Associated Technology Application Projects

- Bridgewater State College: Remote-Sensing Applications in Transit.
- Technology Services Corporation: Road Network Planning Tool.
- Veridian ERIM International: Remote-Sensing Applications Supporting Regional Database for Transportation Planning.

## INFRASTRUCTURE MANAGEMENT

### Participants

- University of California, Santa Barbara
- University of Wisconsin—Madison
- University of Florida
- Iowa State University

### Associated Technology Application Projects

- Tetra Tech ASL: Facilitating the Operational Efficiency and Growth of Intermodal freight Traffic Application of Remote-Sensing Technology to the Alameda Corridor, Los Angeles, California.
- Orbital Imaging Corporation: Impact of Instant Imagery Access on a Regional Database for Transportation Planning.

# Traffic Surveillance, Monitoring, and Management

**JOEL L. MORRISON**
*Ohio State University Center for Mapping*

Ohio State University is the leader of the Traffic Surveillance, Monitoring, and Management Consortia. The University of Arizona at Tucson and George Mason University are the other members of the consortia. The overall goal of this consortium is to improve the efficiency of the transportation system at the national, state, and local levels by integrating remotely sensed traffic flow data obtained from airborne or satellite platforms and matching them with traditional data collected from ground-based sensors.

The three application areas supported by the consortium are traffic monitoring, traffic management, and freight and intermodal transportation analysis. Nine projects have been selected at the three universities that focus on these topic areas during the first year. I would like to highlight the key issues being addressed in these nine projects.

## SATELLITE-BASED DATA FOR TRAFFIC MONITORING APPLICATIONS

### Proof-of-Concept and Operational Issues

Carolyn Merry at Ohio State University is the lead on this proof-of-concept project, which focuses on the examination of the use of higher-resolution satellite imagery to improve automatic vehicle identification and classification. An initial 1-day test was conducted in September. The ground data was collected, but the IKONOS satellite did not record the remote-sensing data. The test is being rescheduled.

### Statistical Modeling for Traffic Monitoring

Prem Goel at Ohio State University is the lead on this project, which focuses on the combination of vehicle counts from satellite imagery and ground counts to improve estimates of traffic volumes. A program that simulates true and observed traffic volumes on homogeneous highway segments has been developed and is being tested and refined. Work to date indicates that adding the satellite data to the ground counts is beneficial.

### Needs Analysis and Allocation of Imaging Times for Transportation Planning and Management

Mark Hickman and Pitu Mirchandani at the University of Arizona are leading this effort. This project is the investigation of the current data needs for offline transportation planning and online traffic management. Elements examined include the desired frequency of images, location of images, number of platforms, and optimal allocation of observation times. The goals of the project include developing models of platform formations from a single detection at a single point, developing implementations to near real-time for traffic adapting signal control systems, providing information for offline transportation planning, and providing information for online traffic management. A helicopter mission was flown in Tucson in July to collect both digital and still images. The data are used to investigate platoon formation and dispersion models, leading to explicit flow model building. Work is also under way to develop a “moving queue” model for determining the distribution of platoon sizes on a two-lane freeway and a model for allocating “imagers” on network segments.

### Airborne-Based Data in Real-Time Network State Estimation and Traffic Management

Rabi Mishalani at Ohio State University is the lead on this project, which is examining the need for improved estimates of current traffic flow on the state network. The development of a system to extract and track individual vehicles through an intersection has been initiated. Videos of traffic at three intersections are being analyzed. A database is being developed that can be updated in real time using multiple sensors.

### Feasibility of Using Remote Sensing to Monitor Truck Rest Area Availability and Utilization

Michael Bronzini at George Mason University is the lead on this project. The project focuses on the shortage of parking spaces at rest areas and the overflow of parking at privately owned truck stops that lead to serious problems affecting driver fatigue and highway safety. The problem is to identify truck rest areas, to measure their utilization rates using remotely sensed imagery, and to correlate the results with existing databases. Data on truck and rest area utilization is being gathered and analyzed to provide areawide coverage and predicted utilization, develop real-time inventories, and near-time information on parking availability. Existing images have been obtained form the Virginia Department of Transportation.

### Freight and Intermodal Flow Analysis

Morton O’Kelly at Ohio State University is the lead on this project, which focuses on quantifying the impacts of freight movement around intermodal facilities on land use and local freight activity and tracking freight movement on a regional scale. The Columbus Rickenbacker Airport is the intermodal facility being studied. Historical aerial photographs and geographic information system (GIS) files are being analyzed, along with incoming and outgoing freight flow records. The ability to use aerial photographs to predict truck freight flow is being studied. Aerial photographs of truck weight stations are being combined with ground data to develop a method to model truck behavior.

### Spectral Research Program

Richard Gomez at George Mason University is heading this project. The project is developing a spectral signature library of material types accessible through an Internet clearinghouse. It will also examine spectral signatures of image backgrounds that may interfere with the detection or identification of target objectives. Additional spectral technologies and capabilities to meet transportation needs will be identified. Spectral and other databases are currently being investigated.

### Validation of Remote-Sensing Techniques for Traffic Flow

This project is examining the potential to detect, monitor, and map vehicles on local and regional scales. Robert Schowengerdt at the University of Arizona is the lead on this project. Aerial imagery, local spectroradiometric instruments, and IKONOS imagery are being used to develop a spectral library of vehicle paint signatures for use in identifying individual vehicles. The digital and still images obtained from the helicopter flight in the third project are also being used in this study.

## TRAFFIC MANAGEMENT: SENSOR AND PLATFORM ISSUES

Dorota Brzezinska at Ohio State University is the lead on this project. The project focuses on exploiting recent developments in all-digital data-acquisition sensors to better meet transportation engineers' need for timely and accurate data for traffic flow mapping, monitoring, and management. A conceptual framework for the optimal fusion of multisensor, multiplatform data for transportation needs is also being developed. Work to date includes planning for an initial flight to collect light detection and ranging (LIDAR) and high-resolution data, ground testing of Kinematic hardware to determine the instrumentation requirements for the airborne collection of traffic flow data, and evaluating the performance of Global Positioning Satellite (GPS)/Inertial Navigation System georeferenced data collection.

The technology application partners in the consortium include Technology Services Corporation, Veridian ERIM International, and the Moakley Center for Technological Applications at Bridgewater State College. Near-term plans focus on completing existing research projects, exploiting the initial links with the technology applications partners, convening a meeting of researchers from the consortium universities, and investigating new initiatives with potential partners. The Internet address for the consortium is http://www.cfm.ohiostate.edu/info/NCRST_F/ncrst-f.html.

# Environmental Assessment, Integration, and Streamlining

**ROGER L. KING**
*Mississippi State University*

The Environmental Assessment, Integration, and Streamlining Consortium includes four universities and four technology application partners. Mississippi State University is the leader of the consortium. Other participating universities include the University of Alabama in Huntsville, University of Mississippi, and Auburn University. The technology application partners are Universities Space Research Association, the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center, EarthWatch, and Intermap Technologies Corporation.

The primary mission of this consortium 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 to measure, monitor, and assess environmental conditions in relation to the transportation infrastructure.

The four goals of the consortium are to

1. Develop innovative remote-sensing technology solutions for the assessment of impacts of transportation on the natural environment and the protection and enhancement of the environment;
2. Assess and plan, in particular the capabilities of new high-resolution multispectral sensors, and develop the tools necessary to extract information content from remote observations in an efficient manner;
3. Streamline and standardize data processing of information necessary to meet federal and state environmental regulations and requirements; and
4. Increase the awareness and understanding of remote-sensing technologies and products through workshops and educational materials.

We feel there are at least three critical elements to the success of this consortium. The first element is to identify the transportation stakeholders and their information needs. Second, we must understand the information needs that can be met with remote sensing and geospatial technologies. The final key to success is to understand the accuracy needed and the variance permitted in the environmental impact statement process.

The environmental regulatory process is very complex. There are numerous environmental rules and regulations involving multiple federal, state, regional, and local agencies. Determining how remote-sensing applications can enhance environmental planning, mitigation, and monitoring is not easy, but there are a number of applications that appear to hold great promise. Remote sensing may be useful in the consideration of environmental regulations.

Remote-sensing technologies can provide the type of data needed in the environmental permitting process. Multispectral and hyperspectral imagery can reduce the need for field surveys to identify vegetation cover and to locate wetlands. Terrain data can be obtained through

LIDAR and interferometric dynthetic sperture radar. Orthophotos can reduce the need for detailed planimetric mapping, and airborne GPS and internal measurement can reduce ground control and can accelerate delivery time of all mapping products. Remote-sensing technologies must be proven credible for environmental applications, with proven performance measures and benchmarks, before they will be used on a wide-spread basis.

Three initial study areas have been selected to date. Atlanta is a study area for metropolitan and watershed applications. Wetlands, coastal zones, and intermodal applications are being examined along the Mississippi Gulf Coast. Oxford, Mississippi is the air quality study area. Two other study areas, the Atlanta–Memphis corridor and the Memphis area, are being considered. Available remote-sensing data are being examined in these areas for application to specific environmental issues and regulations.

The Global Hydrology and Climate Center is examining land use changes in the Atlanta area through the use of Landsat images. The center is a partnership among organizational elements from NASA Marshall Space Flight Center, the University of Alabama in Huntsville, and the Universities Space Research Association. The center has already done a good deal of work examining the heat island effects and air quality issues in the Atlanta region. The current project is able to use the remote-sensing images from these past efforts.

The projects at Mississippi State University are using Landsat imagery and other remote-sensing technologies to examine environmental features along the Gulf Coast. Hyperspectral images are being used and LIDAR data are available for the New Orleans area. Hyperspectral flight lines have been established for the Interstate 10 corridor and for Ship Island, a national monument in the Mississippi Sound.

We are also looking at the scale needed for different types of environmental applications. For example, whereas Landsat images are appropriate for regional studies, they do not provide the scale needed for site-specific detailed environmental design work.

Projects at the University of Mississippi are examining the use of remote sensing in air quality assessments. LIDAR systems are being used to monitor air quality and emission levels. Oxford, Mississippi, is serving as the case study area for the air quality assessments.

Consideration is also being given to GIS-based planning tools. Existing GIS-based watershed tools are being examined and modified for use in transportation applications. The intent is to make these tools available to practitioners as they are completed.

More information on the activities of this consortium is available on our website at http://www.rstc.msstate.edu/NCRSTE/.

# Transportation Infrastructure Management

**MICHAEL GOODCHILD**
*University of California, Santa Barbara*

It is a pleasure to discuss the Transportation Infrastructure Management Consortium. The University of California, Santa Barbara, is the leader of the consortium. The University of Wisconsin—Madison, Iowa State University, and University of Florida are the other academic partners. Digital Geographic Research Corporation and Geographic Paradigm Computing, Inc., are also partners.

The universities are addressing research in different areas related to remote-sensing applications with transportation infrastructure. The University of California, Santa Barbara, is focusing on data models for transportation, algorithms, sensor fusion, and integration. Work at Iowa State University is in the area of asset management and applications. Research at the University of Wisconsin—Madison is examining linear referencing and asset inventories. The University of Florida is heavily involved in LIDAR applications.

Nine technology application partners are participating in the consortium. These partners include AERIS, Inc.; ASL Consulting; Bridgewater State College; EarthData International; EarthWatch, Inc.; ICF Consulting; Orbimage; Technology Service Corporation; and Veridian/ERIM. A steering committee, comprised of individuals from remote-sensing companies, universities, and transportation agencies, is providing guidance on key transportation issues and potential research projects and assisting with outreach and deployment efforts.

Infrastructure management involves systematic planning, design, construction, maintenance, operation, and renewal of such assets as pavements, bridges, pipelines, rail lines, harbors, and airports. Information on the location and the condition of these assets is critical to effective decision making. The consortium is examining the use of remote sensing to document the location and condition of transportation infrastructure assets.

Like the other consortia, we are placing a major emphasis on consultation with transportation agencies and other groups. Initial research projects are under way based on preliminary consultations with these groups. The consortium will work to transfer research results quickly back into practice. Thus, the consortium is following a cyclical process of consultation, research, outreach, and back to consultation.

Many of the consortium's research projects focus on combining remote sensing with other spatial information technologies. Many of the consortium's projects are concerned with the way remote sensing integrates with GISs, GPS, and other technologies.

The consortium undertook a number of activities to facilitate the consultation process. A conference was held in California in October 2000, and plans are under way for more local and regional conferences. In addition, numerous one-on-one consultations have been held with different transportation groups.

One objective of the consortium is to first identify the major priorities of state transportation agencies and then to match remote-sensing capabilities to help address these priorities. Possible implementation issues and budget implications are also being examined.

The consortium is looking for cooperative outreach projects that emphasize problems of implementation, cost-benefit, and risk reduction. Partnerships with state departments of transportation and private sector groups are being developed. The consortium is also heavily focused on curriculum design. Information on the consortium is available through our website, and we have published a brochure.

We are using *Technology Transfer Quarterly* in Florida, which has a circulation of about 18,000, to publicize the activities of the consortium. We are also very interested in inter-Consortium activities. The University of California, Santa Barbara, is responsible for synthesizing the work of all four consortia.

Other activities under way focusing on practitioners include the development of a transportation remote-sensing glossary, contact list, data director, catalog of available private sector services, and bibliography. A search engine technology is being used to develop the bibliography.

An initial set of research projects has been identified and is under way. These priorities may change as more input is received from the various transportation user groups. There are three research projects under way at Iowa State University. These focus on remote sensing for access management, identifying intersection attributes, and addressing spatial accuracy issues.

Concerns associated with access management include balancing accessibility and mobility with access and safety trade-offs. Access control statistics indicate that the crash rates are lower when there is greater access control. No comprehensive inventory exists, however, of the relationship between crashes and access. This research project focuses on the exploration of the application of remote sensing to address this gap.

Examples of factors that contribute to access-related problems include driveways and turn lanes. The research project will use remote sensing to identify these types of physical features and will try to relate them to crash data. Steps in the study include identifying the features of interest, collecting ground truth data, extracting features from imagery, estimating quality of access, correlating those measures with crash rates, determining the kinds of data required, and working with partners on automating the process and transferring it into practice.

There are two projects under way at the University of California, Santa Barbara. The first is examining the use of various techniques, including hyperspectral imagery, to identify roads and roadway surface types. It is possible to get fairly high-resolution images that can be used to identify different pavement types, parking lot surfaces, and building roof surfaces. One of the objectives of the study is to be able to identify pavement type and, from that, pavement quality and advance warning of pavement deterioration. Work is under way to develop an inventory of spectra for different pavement types. Ultimately, it is hoped this spectra inventory can be linked to images to differentiate pavement types.

Most of the work under way at the University of Florida focuses on the application of LIDAR to transportation. For example, LIDAR is being used to improve the ability to create orthophotos by using LIDAR-derived elevation data combined with imagery. One application is applying LIDAR at the St. Petersburg, Florida, airport to develop a vertical profile of the runway approach.

One project at the University of Wisconsin—Madison is mapping bridge locations in the state using remote sensing. All of the bridges on the state trunk highway network are being identified and inventoried. The state bridge registry is being improved by adding critical location data through the use of remote sensing. Sophisticated approaches for detecting bridges from imagery are being applied. Templates are being used to identify bridges, and artificial intelligence techniques are being applied to process the imagery and locate bridges accurately.

Another project under way at the University of Wisconsin focuses on the derivation of driving distances from the imagery. The issue examined is that distance-measuring devices mounted in vehicles respond differently to factors such as the slope of terrain. The slope can be automatically detected in imagery using digital elevation models. A much better estimate of driving distance can be provided from remote sensing than from more traditional techniques.

The second project at the University of Wisconsin is using imagery to enhance and update road network data. In some cases, imagery may be used to improve the positional accuracy of existing databases, while in other cases it may be used to update databases in areas undergoing rapid development.

I look forward to productive discussions during the conference. We strongly believe that consultation with the transportation community is a key to the success of the consortium's work. I would invite you to look at our website for more information on specific research projects. The geographic distribution of the four universities involved in the consortium provides an efficient way to reach transportation agencies throughout the country. We are using the Internet very extensively for outreach activities, and we would appreciate any feedback you might have on other methods we should be using.

More information on the consortium is available at our website (http://www.ncgia.ucsb.edu/ncrst/).

# Disaster Assessment, Safety, and Hazards

**STANLEY A. MORAIN**
*University of New Mexico*

The University of New Mexico is leading the Disaster Assessment, Safety, and Hazards Consortium. The University of Utah, Oak Ridge National Laboratory, and George Washington University are the other academic partners in the consortium. Product demonstration partners are AERIS, Inc., and EarthWatch, Inc.

The focus of this consortium is on using remote sensing to improve planning, mitigating, and responding to hazards and disasters that threaten the transportation system. Highways, roadways, railroads, rivers, canals, ports, airports, and pipelines are all susceptible to hazards and disasters. These transportation lifelines are critical links in responding to hazards and disasters. Projects at the consortium focus on integrating remote-sensing data into the transportation and disaster information systems to enhance planning for hazards, mitigating potential problems before they happen, and responding to those that do occur.

The examples of applications of remote sensing examined by the consortium are updating and maintaining transportation lifeline databases, updating Emergency 911 information, evacuation modeling, and identifying areas on rural roadways susceptible to disasters. A survey of remote-sensing applications in transportation is also being undertaken.

I would like to review the work under way at Oak Ridge National Laboratory in road network extraction and model development. The project at Oak Ridge National Laboratory focuses on the use of remote sensing with road models. The imaging properties of roads include aerial photography and hyperspectral data. The spectrum of road surfaces and the deterioration of road surfaces are being examined to assist with roadway management and maintenance. The intent is to identify what the different roadway deterioration patterns look like in hyperspectral imaging.

Road-following systems are also being examined. Being able to follow a roadway in a heavily forested area is difficult with current technologies. We hope to test some of these applications in Salt Lake City (Utah) before the Olympics. We have another opportunity with the University of Utah, Utah Department of Transportation, and emergency management systems to address some very near-term issues associated with the 2002 Winter Olympics.

The University of Utah is examining the application of remote sensing to develop, update, and maintain lifeline databases. Emergency management plans are developed around the existing roadway and transportation system. In rapidly developing areas, these plans are quickly out of date and inadequate. The loss of a lifeline poses life-threatening concerns. Remote-sensing technologies are being examined for the application in maintaining and updating Emergency 911 transportation networks and other lifeline systems. Techniques and guidelines for the use of high-resolution satellite data for updating 911 and other emergency services are being developed.

A project at George Washington University is developing an annotated bibliography for remote-sensing applications. This annotated bibliography is on the consortium website.

Currently, there are some 1,200 citations in the bibliography. In the future we plan to develop and post on the Internet short fact sheets on the use of remote sensing for specific transportation applications.

The Oak Ridge evacuation model is based on database and modeling strategies. Work is under way to develop an interface to put the data into a GIS-compatible system. The system will be tested in Utah. More information on the consortium is available at http://trans-dash.org.

# Traffic Surveillance, Monitoring, and Management

**MARK HALLENBECK**
*University of Washington*

I would like to thank Anita Vandervaulk, Manager of the Transportation Statistics Office at the Florida Department of Transportation, who served as the cofacilitator for the two Traffic Surveillance, Monitoring, and Management breakout sessions. We had lively discussions in both sessions, and I would like to thank all of you who attended.

The discussion in both breakout sessions focused on what is useful and what is not useful about remote sensing as it applies to traffic surveillance and the potential benefits of the nine research projects currently under way. We also identified the important elements missing from current research efforts. Finally, the groups considered approaches to enhance implementation of remote sensing with traffic surveillance.

We started out by examining the current processes for introducing new ideas, technologies, and techniques at state departments of transportation and other public agencies. We looked at what elements are necessary for change to take place. If an agency or an individual is going to change, something better must be available. There has to be a reason to take the time and the effort to change.

Transportation agencies collect and analyze a great deal of traffic data now. Transportation professionals know the advantages and the limitations of these data. Although they may not always be the best data, they are "our" data and a known quantity, while remote sensing has great appeal and is an unknown quality. Transportation professionals need to become comfortable with the accuracy, cost, and utility of remote sensing before it will be used on a widespread basis.

Traffic staff must be shown that remote sensing provides the same data less expensively than current practices, provides better versions of the same data for the same price, or provides new useful data. One area in which remote sensing may be able to provide new data is measuring and monitoring trip reliability. Additional research and demonstration projects focusing on this topic would be beneficial.

There was general agreement in the two breakout sessions that remote sensing for traffic surveillance is not ready for near-term implementation. There was interest in research and testing possible applications, but participants felt widespread adoption was still well in the future.

The two groups identified areas for further research, demonstration projects, and workforce development activities. First, it was suggested that the technology should not pick the solution to solve. Rather, agency staff with [transportation] problems need to understand available technologies and help identify the critical issues that remote sensing may be able to address.

Currently, traffic professionals do not know enough about what remote sensing can and can not provide. At the same time, remote-sensing professionals do not understand the problems traffic engineers and planners face. Improved communication is needed to promote an ongoing dialog between the remote-sensing and the transportation communities. This conference has been a good starting point for promoting communication and coordination.

There is also a need for a meta data list on the current research projects and other efforts that would include data items provided, time frame involved, accuracy and resolution of the data, costs of data collection, potential to automate the data-collection process, and limitations and weaknesses of the data. Once this information is available, transportation professionals can start to provide better feedback to the remote-sensing community. It is important to remember that the data needs of transportation professionals vary greatly depending on their roles and responsibilities. Planners, traffic engineers, and operations personnel all have different data needs. There are some common data requirements, however, and joint use of data can help reduce costs. It takes time to build consistency among the different groups sharing data, however.

Transportation professionals also want to know what data are available now and what will be available in 5, 10, and 20 years. It is critical to provide realistic expectations related to the availability, accuracy, and cost of remote-sensing products and services. This information will allow transportation agencies to focus expectations and to start identifying funding needs.

Areas identified for future research include the use of remote sensing for measuring and monitoring trip and travel time reliability, alternatives to helicopters and planes for air-based data-collection platforms, and incorporation of remote sensing within the intelligent transportation system architecture.

It appears that greater resolution is needed for traffic applications than is currently provided by satellite imagery. Airplanes and helicopters are too costly for most public agencies. Research on a pilotless remote airplane is needed, along with research on liability and failsafe operations. There is also a need for descriptions that all levels within public agencies can understand. Using websites is a good way provide current information to all interested groups.

# Environmental Assessment, Integration, and Streamlining

**Leni Oman**
*Washington State Department of Transportation*

I would like to thank Lawrence Friedl of the Environmental Protection Agency, who served as cofacilitator for the two breakout groups. As you know, state departments of transportation are facing numerous changes and challenges related to evaluating, mitigating, and monitoring environmental impacts.

There are more environmental regulations at all levels of government. There is a strong push to integrate environmental considerations earlier in the planning process. Agencies are also required to consider a wide range of environmental issues, including those related to species and habitat, land use, and social justice. More emphasis is placed on environmental stewardship, not just meeting environmental regulations.

Environmental factors are present in all phases of transportation, from planning projects to maintaining facilities, and the list of stakeholders continues to grow. There is also pressure to streamline the environmental process. There is not a cohesive vision of what streamlining means, however. To many people, streamlining means faster decisions and fewer regulations. To others it means better decisions or decisions that stick.

The 60 participants in the two breakout sessions used these issues as a backdrop to discuss remote-sensing applications to address environmental concerns. We started by examining three areas. First, we wanted to identify the critical issues associated with conducting environmental assessments. Second, we discussed which of these issues might benefit from remote-sensing products and services. Third, we identified possible research projects and priorities.

Three major categories emerged from these discussions. We first identified subject areas for potential applications of remote-sensing products and services. The second category reflected process issues. The third category addressed data needs related to the different transportation planning phases.

A number of subject areas were identified for possible remote-sensing applications. Topics included the National Environmental Policy Act of 1969 streamlining process; watershed assessments; wetlands, water quality, and storm water issues; land use changes; air quality; species; floodplain management; environmental justice; and cultural resources. More detailed issues were identified within some categories. For example, within the species category, concerns identified included road kill, habitat, and biodiversity data. A logical next step would be to define the specific issues within each category and to identify common data needed to develop a strategic plan for the environmental area.

Scale was raised as a significant issue with the data needs discussed in both groups. The scale needed for planning purposes is likely to be different from the scale needed for design and permitting purposes. There is a need for better data in these two areas, and remote sensing may be able to help provide information cheaper and faster than other methods.

Many states do not have a comprehensive soils database. Soil moisture is another issue that we do not currently have good data on. Riparian data is needed for analyzing salmon recovery, which is a major issue in Washington State. Currently, there is no database for riparian quality.

Information on imperious surface areas is important in storm water assessments. There is again, little data available on imperious surfaces.

Air pollution and air quality are critical issues in most major metropolitan areas. A desire was expressed for data on the sources of air pollution and the airsheds affected. Remote sensing may be able to provide this type of data. Finally, better resolution of data in a number of areas was identified as a need.

A number of environmental process issues were also identified for consideration before remote-sensing applications can be used on a widespread basis. A critical process issue is that remote-sensing data must be accepted by regulatory agencies or state transportation agencies will not use it. The accuracy of the data and the level of accuracy required in the regulatory process are important.

Real-time data would also be beneficial to many environmental assessments. For example, continuous flow models are beginning to be used in storm water analysis. Remote sensing may be able to provide the data needed for these models. A data directory would also be beneficial. An effort is under way to develop a statewide directory. This effort is a good first step, but more information on projects and success stories is needed.

Metrics and measurement tools represent another area in which remote sensing may enhance current environmental assessment procedures. These measurement tools cut across all the subject areas identified previously. Benefit-cost information is also needed on remote-sensing products and services. Transportation agencies need to know the costs associated with different applications.

Two-way education is also needed. The remote-sensing community needs to better understand transportation environmental issues, and transportation professionals need more information on remote-sensing tools and techniques. Ongoing communication using all available methods should be a priority.

As noted previously, there are different data scale needs associated with environmental requirements related to the various phases of transportation planning, program management, budgeting, project development, design, construction, maintenance, and operation. The correct scale must be matched to each application.

Other than the use of aerial photography, participants did not identify instances in which remote sensing is used in the environmental area. Possible applications related to storm water were discussed. Storm water issues associated with transportation projects focus on possible water quality impacts, proper function and condition of the watershed, and endangered species. More specific issues relate to the design scale data needs, soils data, land use data, and improved water quality data.

Research priorities were discussed in both breakout groups. Demonstration projects were described as a great way to help reduce the risk for new players in remote sensing. Cost information on the use of remote sensing is needed to identify where and when it is most effective. Measurement tools for both implementation and function would be beneficial.

Documenting that a required mitigation action was actually completed is important. Remote sensing may be able to help monitor mitigation activities for reporting back to the resource agencies that specific actions were actually taken. The watershed function of the mitigation measure is also important to know. This information can help determine if the anticipated benefits are being realized and if the investments in mitigation are worthwhile. Mitigation measures should not be done just to meet a requirement; they should result in an environmental benefit.

Research on scale ability is needed. Nested data approaches, which consider the resolution requirements during the different transportation phases, should be considered.

Providing adequate funding for projects was also discussed. A preference was expressed for focusing funding on fewer high-priority projects. It was felt that this approach would help provide better information on projects with the greatest potential for success. It would also enhance the implementation of research projects. Supporting implementation activities should be included in the scope of research projects.

In conclusion, the environmental consortium and the application projects face a challenge in delivering products that can be used relatively quickly by the environmental community. The discussion in the two breakout groups indicated that there is a good deal of interest in applying remote sensing to transportation environmental issues.

# Transportation Infrastructure Management

**DAVID L. HUFT**
*South Dakota Department of Transportation*

**DAVID M. GORG**
*Minnesota Department of Transportation*

A total of 80 participants attended the two breakout sessions addressing remote-sensing applications with transportation infrastructure management. A number of topics were addressed related to infrastructure and facility management. Topics identified included sign, traffic control, pavement, and road inventories; drainage and drainage structures; integration of airborne remote-sensing data and ground-based remote-sensing data; and underground utilities. The trade-offs between scale and accuracy were also discussed. Identifying the proper scale desired to display the data and the accuracy needed for the assessments were discussed.

The Federal Geographic Data Committee (FGDC) formally adopted the National Standard for Data Accuracy. The accuracy of a data set, survey monument, map, or digital orthophotograph can all be expressed as a distance on the ground. The recommended scale for facility management is 1 in. to 200 ft, with a horizontal accuracy of ±2 ft and a vertical accuracy of approximately ±1 to 2 ft. The recommended scale for environmental design work is 1 in. to 50 ft, with vertical and horizontal accuracy of about ½ to 1 ft.

The greater the accuracy desired, the higher the cost associated with data collection. More information on these guidelines is available at the FGDC website (http://www.fgdc.er.usgs.gov). Resolution is another term that is sometimes confusing. It is important to remember that image resolution is different from vertical and horizontal accuracy.

Discussions in both breakout groups focused on infrastructure business needs that might be amenable to remote-sensing products and services. A number of potential applications of remote sensing were identified. Developing, maintaining, and updating inventories of different infrastructure elements were the most frequently noted application. Basic inventories could be expanded to include condition information on infrastructure elements. Condition information could be as simple as identifying paved roads and the type of pavement. Information on dimensions, such as road width, would also be beneficial.

The potential for inventorying existing routes and designing new routes was discussed. For example, remote-sensing data could be used to help identify the most cost-effective and environmentally friendly alignment for a new route. Other attributes could also be considered in the assessment of alternative alignments.

State departments of transportation are interested in more than just highways and surface features. The potential application of remote-sensing technology with rail and other types of assets, including airports and waterways, was discussed. Data on features above the surface that might affect the path of a plane approaching a runway are critical for airport clearance planning. The depth of the water and how depths are changing due to situation are important for port planning and operations. The location of underground tanks and other hazards is important for land work. Data on drainage, watersheds, buildings, and land uses were also discussed.

The groups took the view that infrastructure management starts during the planning process and continues through the process of developing statewide transportation improvement programs and developing project designs and plans. Infrastructure management covers the ongoing operation and maintenance of a new or existing facility. Monitoring and controlling construction activities were also identified as possible applications of remote-sensing data. For example, construction equipment could be controlled if the coordinates and dimensions of the existing terrain and those of the proposed project are known. This type of application was tested in Sioux Falls (S.D.) this summer.

The technical needs associated with infrastructure applications of remote sensing were discussed. Access to data was identified as the first critical step. Knowing what data are available and how they can be accessed is an important need. The need to be able to integrate remote-sensing and non-remote-sensing databases was also discussed. Most transportation agencies have internal databases or legacy systems. Often times, unique referencing systems are used, which may or may not be related to geographical coordinates and may be unique to the specific agency.

A desire was expressed for integrating remote-sensing databases with design software and other transportation planning and design tools. Currently, there is no connection between remote-sensing data and design software. Establishing this link would have tremendous value to the transportation profession.

Mapping remote-sensing capabilities to different transportation applications was discussed. This mapping should include the accuracy and resolution needed for different applications. This information would help transportation professionals understand how remote sensing can be used on specific projects and would be a good starting point for enhancing communication between the remote-sensing and the transportation communities.

The need to automate the data-extraction process was discussed. Most public transportation agencies have difficulty attracting and retaining staff with expertise in specialty areas, such as remote sensing. Automating the data-extraction and -manipulation processes as much as possible would be beneficial to agencies and would help accelerate the deployment of remote sensing in transportation.

Potential barriers to implementing remote sensing in transportation were identified, and approaches to overcome these problems were discussed. The lack of knowledge about remote-sensing capabilities, available techniques, reasonable expectations, and costs was identified as the number one barrier. A reluctance to change was also noted as a problem. Tangible products and services, better information on available remote-sensing techniques, and successful demonstration projects were all identified as important to overcome these issues.

Workforce and staffing problems were identified as potential barriers. Both groups discussed if state transportation agencies should even try to compete with the private sector in recruiting and retaining staff with expertise in remote-sensing and other specialty fields. There was agreement that transportation agencies need to be judicious in determining what tasks to take on internally and what to outsource.

Licensing issues were mentioned as a potential barrier. Sharing information and images among transportation agencies may require developing new licensing agreements. Cost is also an ongoing issue for public agencies.

Current remote-sensing projects in the infrastructure area were discussed. There was general agreement that the titles and descriptions of these projects need to be rewritten into a language more understandable to the transportation community. All groups would benefit from descriptions that better link projects to the end products and the specific benefits to transportation agencies. Explaining how the individual projects connect into a bigger vision for remote sensing in transportation would be beneficial. Tangible product packages are needed to promote remote sensing at all levels within transportation agencies, from the technical staff to managers and policy makers. These product packages could be used to help promote specific applications with immediate pay-offs.

Addressing integration and standards issues was identified as important for the widespread adoption of remote sensing in transportation. Defining the quality, accuracy, and resolution needed for different applications was identified as critical.

Support was also expressed for pilot projects. These efforts should focus on key issues facing state transportation departments and other transportation agencies. Pilot projects and best practices represent important ways that transportation agencies can be linked into the consortia in a more meaningful way.

Developing and disseminating a National Cooperative Highway Research Program synthesis on remote-sensing applications in transportation was identified as an excellent way to build a better understanding of remote sensing among the transportation community. This approach has been used successfully in the past to foster the use of geographic information systems and other techniques and technologies.

Finally, the link with the private sector was discussed. Most state transportation agencies still have limited experience dealing with the private sector outside the traditional approaches. It will take time to build new and innovative public-private partnerships. Both groups need to learn more about each other, especially their limitations and institutional issues related to public transportation agencies.

Overall, the discussion in both breakout groups was very good. There was a positive attitude that remote sensing has a place in transportation and that remote-sensing products and services can help address critical issues.

# Disaster Assessment, Safety, and Hazards

**BRUCE DAVIS**
*NASA Stennis Space Center*

I would like to thank Ted Jones from the Florida Department of Transportation, who cofacilitated the two breakout groups. We had excellent discussions in both groups on issues and opportunities associated with remote-sensing applications in disaster assessment, safety, and hazards. There was agreement that there is a need to better identify the data requirements for disaster assessment, safety, and hazard application of remote sensing. Research and demonstration projects should flow from these requirements.

The primary concerns expressed by participants in both groups focused on dynamic events. State departments of transportation are concerned with planning, predicting, detecting, and managing dynamic events. These events may include floods, fog, ice, snow, earthquakes, and other actions that may impede any transportation mode. There was agreement that the prediction and detection of these events had to be accomplished in a cost-effective way that improves the databases currently used by most departments. There was also agreement that agency staff need to know how the data are collected, the accuracy and the scale of the data, and the limitations of the data.

Real-time data is needed in the hazard area because extreme weather conditions can be life threatening. The incorporation of remote-sensing data into predictive models that includes meteorological and roadway data was identified as a priority. Data are needed on a scale that can pinpoint problem areas along a specific roadway or other transportation facility.

The ability to conduct postevent assessments was also identified as a priority. This capability is especially important in areas such as California, where mudslides usually follow fires. Thus, knowledge of not only the first event but also of how this event will trigger other actions is needed.

The third priority identified by the groups was the training and equipment needed to use remote-sensing and other advanced technologies. Funding is always an issue with public agencies. As a result, the equipment needed for remote-sensing applications may not be available. Also, agency staff may not have the necessary training or expertise in remote sensing.

Enhancing operating efficiencies was identified as a high-priority area for remote sensing. Possible applications identified including routing response vehicles during emergencies and operating other vehicles such as snowplows.

The groups also discussed potential barriers to implementing these applications within transportation agencies. Linking remote-sensing data into state transportation agency databases and models was identified as a major barrier. The lack of detailed data specifications was also identified as a major problem. Linking remote-sensing data with roadway data may help to provide better real-time information on vehicle movements. These data are needed at different scales from a specific roadway facility to a regional level.

Other barriers discussed included the bureaucratic system, the lack of support for change, the limited budgets, and the lack of knowledge about remote-sensing products by most transportation agency staff. The need for ongoing commitment among all groups interested in remote-sensing applications in transportation was stressed.

# Conference Closing and Future Directions

**DAVID FLETCHER**
*Geographic Paradigm Computing*

It is my pleasure to participate in this closing session. My comments will focus on three overall impressions from the presentations and discussions during the various sessions. The three themes relate to the knowledge gap between the remote-sensing technology community and the various user groups, the ambitiousness and limitations of the conference goals, and the key elements to successfully implement the innovations.

First, as other speakers have noted, there is a knowledge gap between the remote-sensing community and the end-user community. This gap will not be crossed in a single step. Rather, a number of small steps is required to link remote-sensing experts with the various transportation user groups. Most state departments of transportation and other transportation agencies do not have the resources or staff expertise to accomplish these tasks. Public or private partnerships are needed to close this knowledge gap and to introduce remote-sensing products of value to transportation agencies. There is a significant role for existing and new businesses to turn remote-sensing outputs into user-friendly products and services.

The goals for the widespread use of remote sensing in transportation discussed at this conference are both too ambitious and too limiting. Some goals may be too ambitious because technology is not yet available to collect all of the real-time data desired by transportation professionals. At the same time, some goals may be too limiting by focusing primarily on small-scale applications. Current capabilities allow for the collection of extensive data on a global basis. There is a need to lift our eyes up and consider the use of remote-sensing data on a larger global scale. Research should consider how remote-sensing data could be used at regional, national, and international levels.

There are three keys to advancing innovations. First, the innovative product or service must be technically feasible. Second, it must be economically viable. Third, it must be desirable from a market perspective. The remote-sensing community should focus on the first element—ensuring that an innovation is technically feasible—and work with other groups on the remaining two elements.

All groups should look beyond the traditional approaches to research, especially related to transferring results into practice. More effective techniques are needed to transfer knowledge. For example, a model request for proposal for a technical specification would be more beneficial to a state transportation agency than would a research report or paper. These and other approaches should be used to help bridge the gap between research and practice, focusing on data, services, hardware, and software.

# CONFERENCE CLOSING AND FUTURE DIRECTIONS

**Lawrence Christenson**
*Woolpert*

The presentations and discussions during the breakout sessions were excellent. A number of common themes seem to emerge from both the formal and the informal discussions at the conference. I will highlight five points that reflect many of these comments.

First, improved two-way communication is needed between the remote-sensing community and the various user groups. Transportation agencies are interested in remote-sensing products and services that address specific issues. Ongoing dialog is needed to foster a better understanding of these issues among the remote-sensing community and to explain how remote-sensing products and services can be used to address these problems.

Second, partnerships are needed to advance transportation applications of remote-sensing data. The university consortia and industry groups should encourage participation from state departments of transportation and other public agencies in defining critical issues, developing research problems statements, conducting research projects, and transferring the results into practice. The more transportation professionals are involved in all of these steps, the more accepting they will be of the research results.

Third, remote-sensing products and services must be cost effective. The cost savings and benefits must be identified before public agencies will seriously consider widespread use of remote-sensing technologies and services. Benefits may be realized in terms of lower costs, savings in staff time, and availability of new data.

Fourth, the issue of standards must be addressed. Remote-sensing suppliers should make this topic a high priority because public agencies will want assurances that data meet specific criteria. Standards are especially important as they relate to liability issues.

Finally, remote-sensing products and services should be targeted to the various audiences. There is a need to match available information to different levels within an organization, from the technical staff to top management. Individuals at all levels must understand the objectives, costs, and benefits of specific applications.

# CONFERENCE CLOSING AND FUTURE DIRECTIONS

**JEFF TAYMAN**
*San Diego Association of Governments*

It is a pleasure to participate in this session and to provide a perspective from a metropolitan planning organization (MPO). It is important to keep MPOs involved in the discussion of transportation remote-sensing applications. In general, MPOs are planning agencies and do not have the responsibility for operations and maintenance. As a result, MPO staff are interested in the use of remote-sensing data to enhance the planning process.

MPOs are responsible for planning activities at the regional level. It appears that many of the current remote-sensing research projects and applications focus on small areas and specific sites. Research projects applying remote sensing to larger geographic areas and linking regions are needed to better understand the feasibility, costs, and benefits of these applications.

Consideration should be given to broadening the definition of infrastructure to include database development and maintenance. MPOs are responsible for long-range planning and the development of long-range transportation plans. Travel forecasting models are critical tools in this process. These models are data intensive, and good data is critical for good forecasts. Whereas remote sensing is being used in a few instances to enhance forecasting models, much more could be done. Research is needed to examine how remote-sensing data could be used in travel models, including developing and maintaining databases. This need will be even greater once Federal Highway Administration releases the Transportation Analysis Simulation System, the next generation of travel forecasting models.

It is important to provide realistic expectations about remote-sensing technologies and data availability. There seem to be questions about the capabilities of current technologies to meet specific transportation needs and applications. Research focusing on short-term projects, with results that can be used immediately, would be beneficial. At the same time, maintaining longer-term basic research is also important.

There is a need to improve communication and coordination among all the groups involved in remote-sensing research, product development, and technology transfer. There are a lot of activities under way, and keeping all groups informed on the status of different efforts will be important. Developing and maintaining a clearinghouse would be one good approach.

Failures as well as successes should be discussed and highlighted. We can often learn a good deal from research and projects that are not successful. Groups should not be afraid to discuss projects that did not achieve the desired objectives.

Cost-benefit assessments are needed on products, services, and research studies. It is important that realistic expectations are presented and that the benefits of remote sensing are not oversold. Remote sensing may provide data cheaper than current methods, reduce staff costs, or provide new data not previously available.

Finally, it is important that remote sensing focus on critical transportation problems. Technology applications in search of problems or markets will not be successful. As other speakers have noted, remote-sensing professionals need to better understand the issues and problems of transportation agencies. At the same time, transportation agencies need better information on the capabilities of remote-sensing and other available products and services. This conference has helped to take an important step in establishing an ongoing dialog among these groups and meeting these objectives.

# CONFERENCE CLOSING AND FUTURE DIRECTIONS

**IAN MACGILLIVRAY**
*Iowa Department of Transportation*

This conference has provided an excellent opportunity to learn more about remote-sensing technologies and applications. New and innovative concepts and approaches to data collection have been discussed. It is a pleasure to provide a few comments from the perspective of a state department of transportation (DOT).

Other speakers have stressed the importance of focusing remote-sensing capabilities on real-world problems. The remote-sensing community needs to gain a better understanding of critical transportation issues as well as the roles and responsibilities of public transportation agencies. At the same time, remote-sensing experts should not be bound by current ways of collecting transportation data. New perspectives on data collection, analysis techniques, and presentation methods are needed in transportation.

A key benefit of the dialog between the remote-sensing and the transportation communities should be the generation of innovative approaches to applying techniques to critical issues. Thinking outside the box, developing new ways to collect current data, and identifying technologies that provide new data should all be encouraged and fostered through the various programs. There may also be opportunities to learn from research in other industries.

It is important to remember that state DOTs have historic views on many issues and are comfortable with older technologies and approaches. Transportation agencies maintain extensive databases on traffic levels, trends, and other variables. Many agencies do not view new technologies and approaches as necessarily better. Staff are often skeptical of new techniques and technologies. The remote-sensing community will need to instill confidence in the validity and the quality of the data. Change is likely to occur slowly rather than quickly because it takes time for agencies to assimilate new data-collection methods and applications.

State transportation agencies and other public agencies are having difficulty retaining staff, especially those with expertise in specialty areas. As a result, internal staff may not always be available with the experience and expertise needed to oversee remote-sensing applications. Partnerships with private-sector firms are needed to help address these limitations. Many public agencies have little or no experience with private-sector partnerships, and it will take time to work out arrangements that both sides are comfortable with.

State transportation agencies will need help from the remote-sensing community and other groups to meet their new roles and responsibilities. Emerging issues related to social justice, environmental justice, and alternative analysis may all benefit from the application of remote-sensing technologies and data.

It is important to keep issues related to data accuracy in perspective and not let it be a barrier to projects and applications. Transportation data are used for a wide range of purposes, including planning, forecasting, designing, operating, and maintenance. The same level of accuracy is not needed for all applications. One approach is to develop a system that can be used in all aspects of transportation policy development, planning, design, operation, and maintenance. My vision of the perfect tool would be an integrated database that includes vegetation, land use, cultural resources, soils, hydrology, and other information that accommodates value-based analysis, not just minimum cost assessments. Such a database would allow staff to apply alternative values with alternative weights for discussions with the wide range of transportation stakeholders.

Duplication of research is not all bad. There is a need for ongoing communication and coordination to ensure that there is not major duplication of efforts, but some overlap can be beneficial because conditions vary in different areas. The development and maintenance of a Geolibrary would provide a convenient link between the remote-sensing industry and the transportation community.

# CONFERENCE CLOSING AND FUTURE DIRECTIONS

**LAWRIE E. JORDAN III**
*ERDAS, Inc.*

It is a pleasure to participate in this closing session. The conference has provided a great opportunity to discuss remote-sensing applications and transportation. I would like to highlight four general themes in my comments.

The first theme, which mirrors comments of other speakers, is that we are in a time of transition. Public transportation agencies are changing in response to new challenges and responsibilities. State departments of transportation and other groups are being challenged to do more with less. Remote-sensing technologies are also evolving and offer the potential to help meet the increased needs of public transportation agencies. The remote-sensing industry is moving toward an "end-to-end" system.

The second theme is a focus on success. As they say in other industries, job number one is maintaining a happy customer. Providing customers with products and services that meet their needs and their expectations is critical. It is also important to remember that you cannot get the right answer if you ask the wrong question. We must get to know the needs of the transportation community better and focus pilot studies on those needs to document the benefits of remote-sensing applications. The results of those pilot studies can be used to provide high-velocity delivery of meaningful products.

It is also important to remember that there is no one right way to do the wrong thing. There is a need to think outside the box and to look at ways to enhance the research and technology transfer process. Remote-sensing products and services have to be easy to get, easy to use, and affordable. There is also a need to empower the end user and to provide distributed processing. Sharing successes, adopting key standards, and using web-enabled methods for sharing information are also important.

The third theme focuses on overcoming barriers. Rather than succumbing to possible paralysis by analysis, the remote-sensing industry should follow the Nike example and "Just Do It." Nothing succeeds like success, to turn skeptics into stakeholders. The old prescriptive methods of procurement are no longer valid, and procurement reform is needed. As other speakers have noted, workforce development is critical. All groups—academia, research organizations, technology groups, and public agencies—have a role and a stake in making workforce development a priority.

The fourth and final theme is that the future of remote-sensing and geographic information system applications in transportation is brighter than ever. The future can be built on a solid commercial software foundation, with desirable research extensions.

## CONFERENCE CLOSING AND FUTURE DIRECTIONS

**JOHN R. JENSEN**
*University of South Carolina*

It has been pleasure to participate in this conference. I would like to focus my comments at this closing session on five general topics. These elements are data continuity, workforce development, knowledge gap, transportation agency information requirements, and digital image-processing software.

In terms of data continuity, transportation agencies should not count on the availability of satellite high-resolution data for near-term operational applications. These capabilities are more likely to be developed over the mid to long range. Future transportation-related remote-sensing applications should be based on a balance of airborne and satellite-borne sensor systems.

Workforce development is a key concern. The availability of staff with expertise in remote sensing is a critical issue. Transportation agencies will either need staff with remote-sensing skills or will have to use consultants and other outside expertise. Currently, there are not enough remote-sensing professionals to meet the demand. Even if transportation agencies outsource these functions, some internal expertise is needed to guide and manage consultants and vendors.

The knowledge gap needs to be bridged between the transportation and the remote-sensing communities. State transportation departments and other agencies should carefully outline their information requirements as a first step to helping to close this gap. Demonstration projects focusing on these requirements should be developed and conducted with the involvement of all groups. The results and success from these projects should be widely disseminated. The successful projects can be showcased, certified, and used as the basis for widespread implementation.

Finally, digital image-processing software needs to be simplified. Software tailored specifically to transportation applications should be developed for use by agency staff.