PARTNERSHIP IN RESEARCH: A COOPERATIVE REMOTE-SENSING RESEARCH PROGRAM

Harold T. Rib, Federal Highway Administration,
U.S. Department of Transportation

To evaluate various remote-sensing systems and analysis techniques for solving specific engineering problems—e.g., soils mapping and detection of seepage zones, landslides, and subsurface cavities—a cooperative remote-sensing research program was developed by the Federal Highway Administration. This program coordinates federal, state, and contract research funded by the Administration and the states. This paper provides an overview of the cooperative research program, describes its development, indicates the type and extent of effort provided by the cooperating groups on the various studies, and briefly summarizes the status of the studies.

•IN RESPONSE to the need to evaluate various remote-sensing systems and analysis techniques and their applicability to highway engineering, the Federal Highway Administration (FHWA) initiated a cooperative remote-sensing research program. This coordinated program includes FHWA staff and administrative contract studies, state research studies using Highway Planning and Research Program (HPR) funds, and also some research efforts by organizations using their own funds (data provided by FHWA).

This paper provides an overview of the cooperative program, describes its development, indicates the type and extent of effort provided by the cooperating groups on the various studies, and briefly summarizes the status of the studies. The details on the establishment of the test sites, the goals of the particular studies, and the results obtained in various aspects of the studies are described in other papers in this Record by Noble, Stallard, West, Wagner, and Dedman and Culver.

REMOTE-SENSING RESEARCH IN THE HIGHWAY FIELD PRIOR TO JUNE 1967

One of the earliest efforts to apply one of the newer aerial sensor systems directly to a highway project was undertaken by the Bureau of Public Roads (now FHWA) in February 1965. HRB-Singer, Inc., under contract to the BPR, performed an aerial infrared survey using a classified sensor over the Rio Atrato Swamp in Colombia, South America. The goal was to locate a feasible route across the swamp. The types of information sought included depth of water, depth to stable foundation, character of sediments, and location of granular materials. The results obtained were negative because of instrument malfunction, adverse environmental conditions, and lack of field control (1).

In March 1965, a study was initiated by the California Division of Highways to evaluate the use of infrared imagery for the investigation of landslides and the location of material sources. This was a cooperative study with FHWA, and HPR funds were used. No imagery was specifically collected for this study. State personnel evaluated infrared imagery collected by other agencies in several different areas of California. The study was completed in early 1968, and the major conclusions reported were that (a) the only promising application noted was that of route location through geothermal areas, (b) security restrictions on instrumentation and imagery were a hindrance to productive work, and (c) much of the equipment used to obtain infrared imagery was in the development stage and subject to considerable operational difficulty (2).

In April 1965, a remote-sensing research program was initiated at Purdue University to determine optimum sensor combinations for the development of master engineering soil plans. This was a cooperative study with the Indiana State Highway Commission and FHWA, and HPR funds were used. It was the first effort in the highway field to evaluate various classified and unclassified airborne remote-sensing systems. The systems evaluated included infrared, radar, and multispectral scanners; multiband camera; and various photographic films.

The first phase of the Purdue study, lasting from April 1965 to December 1966, evaluated the various sensor types over controlled test sites. Also investigated was the development of unique signatures for soils and terrain conditions by means of density measurements on the multispectral imagery—an attempt at semi-automatic interpretation. The major conclusions reported for this phase were that (a) natural aerial color photography was the best single sensor for soils mapping, (b) the optimum combination of sensors for performing detailed engineering soils mapping was simultaneous coverage with multispectral imagery and natural aerial color photography, and (c) the use of multispectral imagery offered the greatest potential for research toward the goal of automatic interpretation (3, 4, 5). The sensors used in this study, with the exception of the aerial cameras, were all classified. This placed a limitation on the publication of the imagery collected by the classified sensors but not on the conclusions derived from the analysis of the imagery.

The second phase of the Purdue study was just being initiated at the time the cooperative remote-sensing research program was developed. Consequently, it was included in the cooperative program.

DEVELOPMENT OF COOPERATIVE REMOTE-SENSING RESEARCH PROGRAM

The results of these early remote-sensing efforts in the highway field as well as research reported in other fields demonstrated the potential value of these systems. They also indicated the need for additional research before many of these sensor systems or analysis techniques could be applied directly to highway projects.

To promote and carry out this needed research, a research program was instituted by the Federal Highway Administration in 1967. The program was entitled "Optimizing Utilization of Natural Resources by Means of Remote Sensing Techniques" and was included as one of the tasks in the National Program for Research and Development in Highway Transportation. The main goal of the program was to investigate the application of various remote-sensing systems for identifying and evaluating natural materials. These systems were to be investigated individually or in combinations both from aerial platforms (to rapidly evaluate large areas) and by field reconnaissance techniques (to evaluate small areas in detail). Concurrent with this effort, computer techniques were to be investigated to aid in the reduction and analysis of the multisensor data.

The accomplishment of a program of this scope required the establishment of several basic criteria.

1. Test sites would have to be established in various parts of the country under a variety of climatic, environmental, and geologic conditions. Conclusions derived from a specific test site would be applicable to local conditions. Generalizing on a regional or national level, however, required the comparison of results derived from several different test sites.
2. Each test site would be a complete unit. That is, a sufficient variety of sensors would be evaluated and certain types of data collected to ensure that a full analysis could be performed—including a computer analysis.
3. The systems evaluated would be those that would generally be available to highway engineers without severe limitations such as security, availability of prototype only, availability of only one source of service, and cost.
4. Liaison would be maintained with various organizations to keep abreast of the latest systems developed. As new sensor systems become available, efforts would be made to incorporate these devices into the test program.

In the establishment of a program of this magnitude, several facts were immediately evident. First, it was not feasible for FHWA to totally fund a program of this size through administrative funds alone. Second, it was improbable that any single highway organization including FHWA had the expertise to evaluate all the various sensors and techniques or the manpower for such an undertaking. Therefore, a prime goal of this program was to develop a cooperative endeavor including FHWA staff efforts, administrative contract efforts, and state efforts either within the HPR Program or with state funds alone.

Fortunately for the development of this program, conditions in the remote-sensing field changed dramatically for the better in late 1967 and early 1968. The data obtained from certain infrared, radar, and multispectral systems as well as some of the systems were declassified, and some of these systems became available commercially. This made it easier to obtain the necessary coverage without the horrendous problem associated with classified data and security clearances. This added impetus to the promotion of the cooperative remote-sensing program.

In the initial planning, it was estimated that approximately 6 to 8 test sites would be required throughout the country in order to properly evaluate the sensor systems on a local and a regional basis. In early 1967, only 2 state HPR remote-sensing studies were in progress: the second phase of the Purdue University study and the California infrared study. The Purdue study met all the desired goals of this program and was included as one of the test sites in the program. The California study was in the process of being phased out and was not included as one of the test sites. Thus, there was a need to establish additional test sites.

PARTICIPATION IN COOPERATIVE RESEARCH PROGRAM

Test Sites

The development of additional test sites required that aid be sought from state highway departments. Several of the states responded to this need; by 1970 cooperative test sites had been established in Kansas, Pennsylvania, and Virginia, and preliminary efforts had been initiated in Maine, Massachusetts, New Hampshire, and New York.

The first test site to be established was in Pennsylvania. Multisensor flights were obtained over this site in May 1969 and again in August 1969. This was followed by the establishment of test sites in Kansas and Virginia where flights were made in 1970. Table 1 gives a brief summary of information on these 3 test sites and the Indiana test site. Included are the types of sensor data obtained, the agencies collecting the data, and a brief description of the test site and the problems investigated.

A cooperative multisensor flight program was carried out in the northeastern states in June 1969. The state highway departments of Maine, Massachusetts, New Hampshire, and New York had selected preliminary test sites in their respective states. The Rome Air Development Center, U.S. Air Force, flew the multisensor mission but was only able to obtain multiband and infrared imagery coverage over selected areas in 3 states—New York, New Hampshire, and Maine. This program was an initial effort to obtain some remote-sensing data coverage for preliminary evaluation prior to the establishment of full-scale test sites. There were some problems encountered with camera operation and test site coverage. Therefore, no extensive analysis of the data could be performed.

Nature of FHWA-Contract-State Participation

The nature of the participation by the various cooperating organizations is complex but flexible. It varies from full support and funding by state HPR funds (Indiana) to practically full support and funding by FHWA (Pennsylvania). The principles guiding the degree of participation by the cooperating organizations are the basic requirements for establishing test sites previously described. Those portions of the program not funded by state funds were funded by FHWA.

The responsibilities of the respective organizations in these cooperative studies are generally as follows:

1. The state highway departments select the test sites, obtain the aerial photographic coverage, provide support for the ground data collection, perform the visual analysis, participate in the preparation of the final report, and in some cases fund the multisensor imagery coverage;
2. FHWA is generally responsible for the overall coordination of the program, aids the states in selecting the test sites, aids the states in the gathering of ground support data and in the visual analysis of the data, participates in the computer analysis of the data, contracts for the collection of the required multisensor imagery coverage when not funded by the states, contracts for the computer analysis of the data by various analysis techniques, and prepares the final report in conjunction with the state; and
3. The contractors responsible for the imagery collection also participate in planning the flight missions, and those that perform the data analysis also participate, where possible, in the collection of the ground support data.

Figure 1 shows the total proposed funding committed to this cooperative program and the amounts expended to June 30, 1971, by the 3 major funding sources: FHWA staff funds, FHWA contract funds, and state HPR funds. Some state non-HPR funds have also been expended on these studies but are not included because of the difficulty in obtaining reliable estimates.

Analysis of Data

One of the major problems in a multisensor project is the analysis of the large quantity of data obtained. For example, in the Kansas test site 74 different sets of data were collected over just 1 test area; a total of 140 different sets of data were collected over 5 test areas. The analysis of this volume of data is a long and tedious process.

As previously indicated, 2 types of analyses are performed: a visual analysis and a computer analysis. The states generally perform the major portion of the visual analysis, and FHWA has the major responsibility for the computer analysis.

The need to develop new techniques to analyze large quantities of data was realized when the cooperative program was being developed. Consequently, FHWA concentrated its major staff and contract efforts in the area of data extraction and analysis by computer techniques. A staff study entitled "Feasibility of Automatically Identifying Terrain Features and Natural Materials From Remote Sensing Data" was instituted in July 1968. This study was programmed for a 5-year period. In this study the major computer analyses are performed under contract to several different organizations. The staff effort includes the selection of the areas to be evaluated and the comparative analysis of the various computer techniques being investigated. The goals of these research efforts are (a) to uniquely identify the pertinent soils and terrain conditions, (b) to develop techniques that will automatically identify and map those features for the entire test areas with a reasonable degree of accuracy, and (c) to try to delineate anomalous areas and determine the reason for the anomaly. Some results of these contract efforts are reported in this Record by West and Wagner.

STATUS OF COOPERATIVE PROGRAM

Indiana

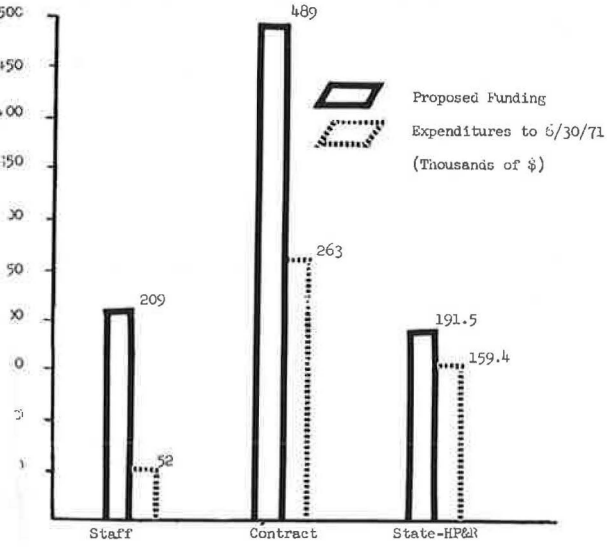
The second phase of the Purdue study was performed during the period January 1967 to June 1969. This phase of the study evaluated the optimum sensor combinations suggested in the first phase for performing engineering soil mapping over a 70-mile (112.7-km) highway project. Also investigated were some of the relative cost aspects of such an approach and the use of digital computer techniques to develop computer-generated maps of soil and terrain conditions. The computer techniques used were those developed by the Purdue University Laboratory for Application of Remote Sensing (LARS). The work in the second phase of the Purdue study was the first attempt to automatically identify and map engineering soils.

Table 1. Cooperative test sites.

State	Number of Sites	Total Length (mile)	Dates Flown	Sensor Coverage Obtained[a]						Agency[c]	Description of Site and Problems Investigated
				Aerial[b] Photography	Multiband	Infrared Imagery	Multichannel	Microwave Radiometry	Microwave Scatterometry		
Indiana	1	70	4-67	X	–	–	–	–	–	ISHC	Humid, temperate climate; rural; glacial, alluvial, eolian, and residual soil and sedimentary rock; soils mapping
			5-67	X	–	–	–	–	–	ISHC	
			4-67	–	–	–	X[d]	–	–	UM	
Pennsylvania	1	48	5-69	X	–	–	–	–	–	PDH	Humid, temperate climate; rural; alluvial and residual soils and igneous, sedimentary, and metamorphic rock; soils and materials mapping and seepage zones
			5-69	X	–	–	X[f]	–	–	UM	
			8-69	–	–	X[e]	–	–	–	RADC	
Kansas	5	47	3-69	X	–	–	–	–	–	KSHC	Humid, temperate climate; rural and urban; alluvial, glacial, eolian, and residual soils and sedimentary rock; soils mapping, subsurface cavities, and pavement condition
			7-69	X	–	–	–	–	–	KSHC	
			9-69	X	–	–	–	–	–	KSHC	
			3-70	X	–	–	–	–	–	KSHC	
			3-70	X	X	X[f]	–	X[f]	X[f]	RSI	
			3-70	–	–	–	X[e]	–	–	UM	
			4-70	X	–	–	X[d]	–	–	UM	
Virginia	1	24	4-70	X	–	–	–	–	–	VDH	Humid, temperate climate; rural; alluvial and residual soils and sedimentary rocks; seepage zones, landslides, and soils mapping
			4-70	X	–	–	X[f]	–	–	UM	
			9-70	X	–	–	–	–	–	VDH	
			9-70	X	–	–	X[f]	–	–	UM	

[a]All photography flown in daytime only. All imagery collected on magnetic tape except that collected by RADC.
[b]At all test sites, black-and-white, natural color, and infrared color were obtained.
[c]ISHC = Indiana State Highway Commission; UM = University of Michigan; PDH = Pennsylvania Department of Highways; RADC = Rome Air Development Center, U.S.A.F. (classified); KSHC = Kansas State Highway Commission; RSI = Remote Sensing, Inc.; and VDH = Virginia Department of Highways.
[d]Daytime.
[e]Nightime.
[f]Daytime and nightime.

Figure 1. Funding and expenditures for cooperative remote-sensing program.



The major conclusions reported for this phase of the study were that (a) natural color aerial photography was the best single sensor for preliminary engineering soils mapping, (b) multispectral imagery was a supplement to color aerial photography, and (c) computer analysis of multispectral imagery offered a powerful tool for analyzing the data and automatically distinguishing certain soil and terrain features (6, 7). A report was prepared by Miles (8) summarizing the major aspect of the work performed and the conclusions obtained in the 2 phases of the study.

Pennsylvania

The visual analysis of the data and the delineation of the major land forms were performed by FHWA. Several subareas were selected for detailed investigation along the first 24 miles (38.6 km) of the 48-mile (77.2-km) flight line, and a computer analysis was performed. Under an FHWA administrative contract with the Infrared and Optics Laboratory at the University of Michigan, analog computer techniques were investigated by the use of the SPARC system. Analyses of several subareas were completed, but a final classification by this technique was not attempted. Some of these same subareas were investigated by digital computer techniques under an FHWA administrative contract with LARS; LARSYSAA system was used. West reports in this Record on the results obtained for one of the subareas. A doctoral candidate at Pennsylvania State University selected a portion of the Pennsylvania test site for his research—a cooperative but nonfunded effort with FHWA. The researcher mapped in the field a portion of the site and defined agriculture soil units. He then analyzed the photography and used clustering and digital techniques to perform computer analyses on the multispectral data at Purdue University and Pennsylvania State University. He reported obtaining fairly good results in identifying by computer techniques the various agriculture soils exposed in bare fields (9).

Kansas

Five test areas were flown in the Kansas program: a 27-mile (43.5-km) test area in Jefferson County for soils mapping; a test area in Kansas City, Kansas, for investigating subsurface cavities; and 3 test areas for evaluating pavement conditions. Stallard reports in this Record on the visual analysis of the photography and imagery being performed by the Kansas State Highway Commission. Wagner reports on the investigation of the soils test area in Jefferson County performed by the use of analog computer techniques at the University of Michigan under an FHWA administrative contract.

Density slicing and color enhancement of the Kansas City test area based on relative temperature levels on the 8 to 14 micron imagery are also being investigated by Wagner. The purpose of this analysis is to look for temperature anomalies that are indicative of known subsurface cavities. Digital analysis of the Kansas test areas is in progress at Purdue University under an FHWA administrative contract. No results have been reported to date. Microwave radiometry and scatterometry were also collected over the Kansas test areas. The analysis of these data was performed under an FHWA administrative contract by Resources Technology Corporation of Houston, Texas, and is reported in this Record by Dedman and Culver. The scatterometry data were not analyzed because of the presence of excess noise in the data.

Virginia

The visual data analysis was performed by the Virginia Highway Research Council and is reported in this Record by Noble. Analog and digital computer analysis of the data is in progress at the University of Michigan and at Purdue University under FHWA administrative contracts.

Future Test Sites and Studies

It is evident from data given in Table 1 that the test sites evaluated to date are all in the humid, temperate climate zone. These areas contain a lot of vegetative cover and a minimum exposure of bare soil and rock areas. Test sites are needed in the arid

and semi-arid areas where more bare soils and rock areas are exposed. This requirement may be fulfilled by the establishment of a test site in California, scheduled for the fall of 1972.

The overall goal of the project as previously outlined was threefold: aerial remote sensing, field remote sensing, and computer analysis. The major effort to date has been on the aerial remote sensing and computer analysis phases. Little work has been done in the field remote-sensing area. A new study has been undertaken by the Florida Department of Transportation with the goal of determining the optimum array of remote-sensing techniques for detecting the presence of subsurface cavities and for evaluating the stability of bridge foundations crossing these cavity zones. Both aerial and field remote sensors will be evaluated. There has also been an increased emphasis on field remote-sensing surveys in the recent realignment of FHWA's national research program. The details of the new program are described in the next section.

REALIGNMENT OF FHWA REMOTE-SENSING RESEARCH PROGRAM

A new program entitled "The Federally Coordinated Program of Research and Development in Highway Transportation" has been developed to replace the former program, "National Program for Research and Development in Highway Transportation." The main emphasis of this new program is to concentrate the research efforts on operational problems so that the necessary technology can be developed to meet the needs of the practicing engineer and the results can be implemented.

Within the new program the previous task "Optimum Utilization of Natural Resources by Means of Remote Sensing Techniques" was included within the Project "Techniques to Determine Critical Terrain and Environmental Features by Remote Sensing." Included in this project are two tasks: (a) develop aerial exploration techniques and (b) develop field exploration techniques. The emphasis of the project is to determine terrain and environmental features critical to transportation planning, location, construction, and maintenance with a much greater effort now than previously on field techniques.

The present program is essentially included in the first task in toto. However, it includes other areas that are not in the present program; these areas include the identification and quantification of environmental features and the evaluation of satellite photography and imagery. Critical problems planned for investigation under the second task are delineation of subsurface cavities, determination of the landslide potential of the terrain, and prewarning of slope failures. Some research in this area is already in progress. California is completing a study on monitoring subaudible rock noise as a measure of slope stability—a potentially successful method for prewarning of slope instability. A cooperative staff-contract-state field study was performed in Kansas in August 1971 as a follow-up to the aerial effort for delineating subsurface cavities. Ground-based geophysical equipment, microwave radiometers, and a radar-profiling device were evaluated over several test areas to locate subsurface cavities such as mines and sinkholes. The results of the analysis for some of the test areas will be verified by subsequent drilling.

SUMMARY

This paper describes a joint federal-contract-state research program for evaluating various remote-sensing systems and their application in the highway field—particularly for defining engineering soils and terrain conditions. The background on remote-sensing research in the highway field is discussed, and an account of the development of the FHWA remote-sensing research program is described. A brief summary is included indicating the status of the 4 cooperative studies within this program and the type and extent of effort provided by each of the cooperating groups. Finally, a discussion is included on the new FHWA Federally Coordinated Program of Research and Development in Highway Transportation, its major goals, and the place of the cooperative remote-sensing effort in this new program.

REFERENCES

1. Ory, T. R., and Balmer, H. E., Jr. Infrared Imagery Applications in Determining Highway Engineering Data. HRB-Singer, Inc., State College, Pennsylvania, classified, March 1965.
2. McCauley, M. L. Accomplishment Report on the BPR Financed Research Project: The Use of Infrared Imagery. California Division of Highways, Final Rept. on Study D-5-9, March 1968.
3. Rib, H. T. An Optimum Multisensor Approach for Detailed Engineering Soils Mapping. Joint Highway Research Project, Purdue Univ., Rept. 22, 2 Vols., Dec. 1966.
4. Rib, H. T., and Miles, R. D. Multisensor Analysis for Soils Mapping. HRB Spec. Rept. 102, 1960, pp. 22-37.
5. Rib, H. T., and Miles, R. D. Automatic Interpretation of Terrain Features. Photogrammetric Eng., Vol. 25, No. 2, Feb. 1969, pp. 153-164.
6. Tanguay, M. G. Aerial Photography and Multispectral Remote Sensing for Engineering Soils Mapping. Joint Highway Research Project, Purdue Univ., Rept. 13, June 1969.
7. Tanguay, M. G., Hoffer, R. M., and Miles, R. D. Multispectral Imagery and Automatic Classification of Spectral Response for Detailed Engineering Soils Mapping. Proc., Sixth Internat. Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, Oct. 13-16, 1969, pp. 33-63.
8. Miles, R. D. Remote Sensing and Development of Annotated Aerial Photographs as Master Soil Plans for Proposed Highways. Joint Highway Research Project, Purdue Univ., Rept. 15, July 1970.
9. Mathews, H. L. Application of Multispectral Remote Sensing and Spectral Reflectance Patterns to Soil Survey Research. Pennsylvania State Univ., PhD dissertation, Sept. 1972.