Development and Operation of Remote-Sensing Laboratory for a Transportation Department

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There are many ways to develop and operate a transportation-oriented remote-sensing unit, but almost no written information exists on the subject. The use of remote sensing by state departments of transportation varies all the way from many states that use no remote sensing to at least one state that has an excellent and fully operational unit. An effort was made to examine and analyze many approaches to organizing and operating a remote-sensing unit. Some advantages and disadvantages of the more feasible approaches are discussed. Also included is a discussion of personnel and equipment appropriate for the range or scope of the operations envisioned. The success of any organization is directly related to the management and supervision provided; this matter is also given some attention. Certain other restraints (e.g., funding) are recognized and discussed. One must be aware of the difference between management processes and operating restraints, whether directly imposed (such as defined limits) or indirectly imposed through levels of funding or restriction on the size of the staff. Interactive elements involved in the development and operation of a remote-sensing laboratory are included in the discussion.

Many developments have occurred in remote sensing since the late 1940s. More of these developments will become operational in transportation departments as more attention is given to ascertaining and attaining mission parameters dictated by study needs and available equipment. Perhaps the lingering feeling of mystique in the use of remote sensing makes preparation and proper follow-up seem unnecessary. However, when missions are properly planned, interpretation is adequate, and proper care is used in its application, remote sensing becomes a very useful tool. In this respect, remote sensing can be used to reduce cost and to provide for a more efficient overall operation. The success of a remote-sensing laboratory, as in any other organization, depends on management, operational techniques, equipment availability, and quality of personnel.

Many factors, as illustrated in Figure 1, must be considered in establishing a remote-sensing laboratory in a transportation department. Such a laboratory may be operated in many ways and may serve many purposes. Therefore, the assignment of the laboratory to a particular functioning unit is an important decision. Other factors to be considered include level of service to be provided, quality and quantity of studies produced, level of interaction between other units, type of equipment needed, staffing requirements, and cost of setting up and operating the laboratory. Also important are such considerations as type of imagery to be acquired, purpose of the imagery, and extent of the research to be conducted by the laboratory. Firm decisions that relate to some of these factors do not have to be made until the laboratory is operational, and many such decisions will be based on the economics involved.

Some uses of remote sensing have been skirted (not ignored or overlooked) because of their specialized nature. Some sensing devices, such as radar units that sense vehicular traffic and actuate traffic signals or photo cells that operate lights, require neither analysis nor interpretation. These devices are sensors that receive, translate, and perform. Many sensing devices are available in this category, such as sensors on paving machines, infrared and other sensors that read data cards on box cars and packages, vehicle weighing devices, and speed detectors. A remote-sensing laboratory could have an individual with expertise in this area who would know which devices are available and how they could be used.

Another category of sensors can receive data and transmit the data to satellites that then retransmit the data to stations for analysis and output in various forms. Such instruments have been used to track and monitor the condition of fish and animals. Other instruments have been used to monitor vehicle operator response to such things as flashing messages and railroad crossing warning devices. Transmission is usually in the digital mode, but it may be by videotape. Many types of data can be handled this way, including temperature, stream flow, rainfall, and wind speed.

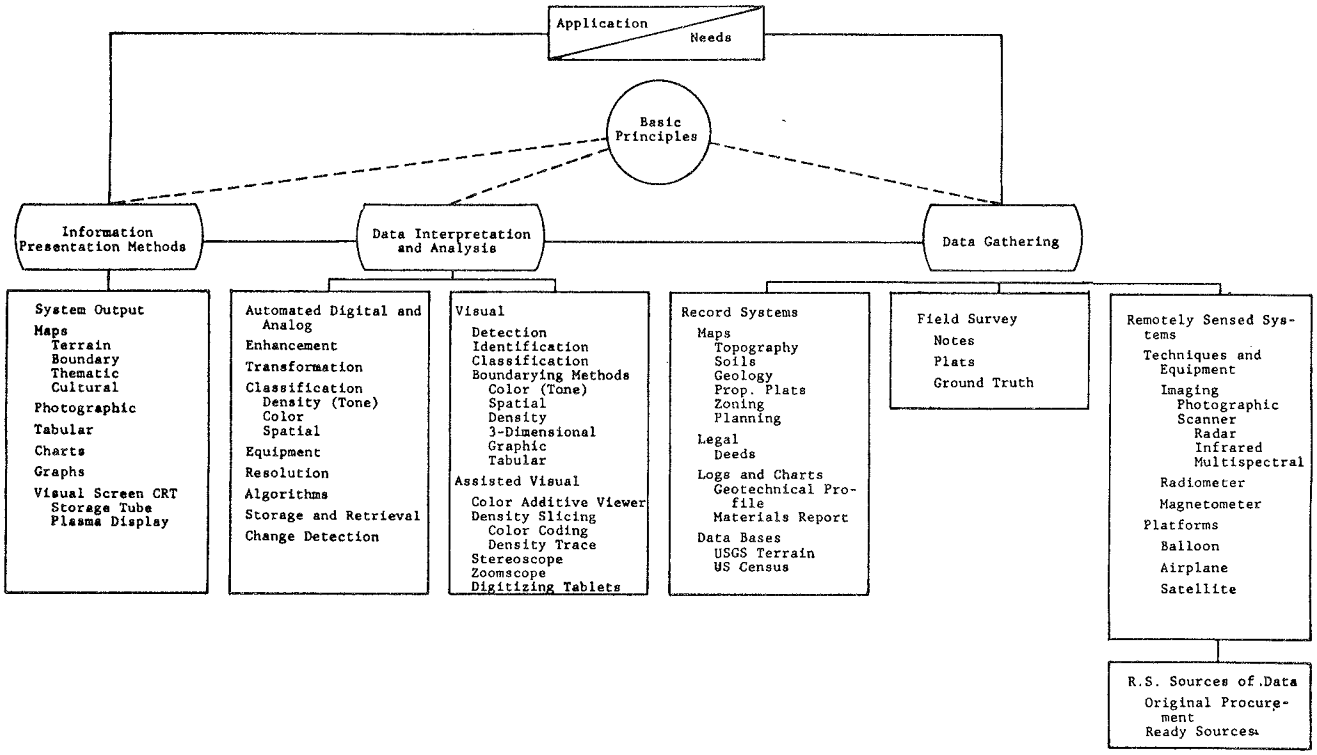
Another category of remote-sensing operations includes video monitoring and photo logging. Video monitoring from remote sites is especially helpful in traffic engineering for monitoring specific sites such as intersections and interchange ramps. Photo logging is used essentially for monitoring pavement conditions and rights-of-way. Still another category of remote-sensing operation involves the use of resistivity, seismic devices, induced polarization, magnetometers, and electromagnetic devices for prospecting and geological exploration. This category also includes nuclear gauges used in soil engineering.

A fully functional remote-sensing laboratory should be prepared to deal with these remote-sensing categories if they are perceived to be of need. They are excluded from further discussion in this paper because of their specific and specialized applications, and they are also excluded from the staffing and equipment costing sections.

In setting up a remote-sensing laboratory or in reevaluating an existing one, a number of factors should be considered. Some of these are enumerated below:

1. What unit or units will most use the services of the remote-sensing laboratory?
2. How will the remote-sensing laboratory administratively relate to other units?
3. What services will the remote-sensing laboratory provide?
4. Will the remote-sensing laboratory provide services for departments other than the transportation department?
5. What level of detail will be provided in data analysis and interpretation?
6. What disciplinary areas (geology, environmental science, archaeology, etc.) will be included?
7. To what extent will ground truthing be carried out?
8. Will the interpreters in each disciplinary area be assigned to the remote-sensing laboratory or to their specific disciplinary units?
9. To what extent will the remote-sensing laboratory be equipped with such instruments as color-additive viewers, density slicers, automated interpretation equipment, zoomscopes, etc.?
10. What will be the laboratory's data acquisition capabilities?
11. Will equipment such as thermal and radar scanners be purchased or rented, or will the imagery be acquired from private companies?

Figure 1. Model for use of remote sensing in transportation information systems.



12. To what extent will high-altitude (U-2 and RB-57) and satellite imagery be acquired, and for what purposes will it be used?

13. To what unit will the remote-sensing laboratory be attached?

HOUSING THE LABORATORY

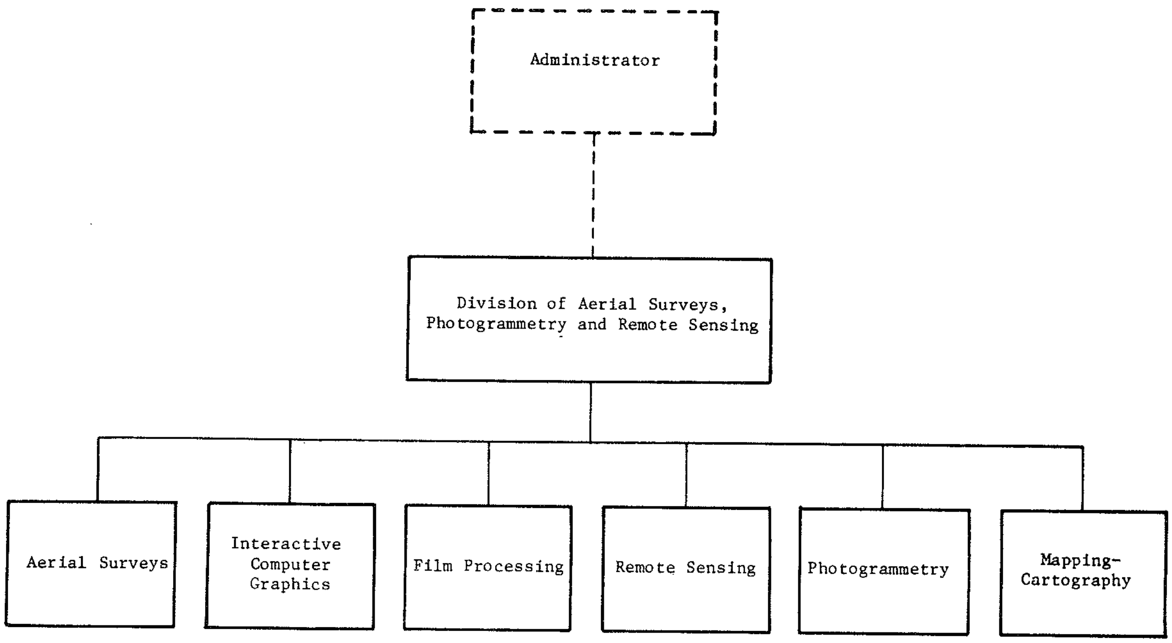
In deciding where to house the remote-sensing laboratory within a transportation department, considerations would include which units, such as geology or environmental science, would benefit most from its service and which units, such as aerial surveys and photogrammetry, would provide the best support activities for the laboratory. One critical factor that affects this decision is whether the laboratory will be limited to providing imagery for other units or if it will provide full services, such as mission planning, interpretative analysis, ground truthing, report preparation, and additional assistance as needed. Where to house the laboratory will gradually evolve as these matters are considered.

The aerial surveys and photogrammetry unit will probably provide the support most needed to sustain the remote-sensing laboratory. This unit will normally have or at least retain some control of the aircraft needed to obtain imagery, the imaging equipment, the processing equipment, the stereoplotters, and the reproduction equipment. Other activities needed to support remote sensing, which are often attached to the aerial surveys and photogrammetric unit, include the mapping, cartographic, and computer-graphics sections. If the aerial surveys and photogrammetry unit does contain all of these sections, then it usually relates well to other units within the transportation department, since it comprises a service unit on which most other units are greatly dependent. When this is the case, the logical place to house the remote-sensing laboratory is with the aerial surveys and photogrammetry unit.

A problem perceived with this setup is that units that specialize in a discipline (such as geology) may not want related personnel (such as geologists) placed separately within the aerial surveys and photogrammetry unit. To overcome possible adversities between units, the remote-sensing laboratory must have the complete respect and cooperation of the other units with which it interfaces. Remote-sensing sections that we observed function best when set up in this manner.

Remote-sensing laboratories can be attached to almost any unit, such as planning, location, or design. Units such as soils and geology may have their own small remote-sensing laboratories that request information from other internal units or hire private agencies to provide the imagery and analysis they need. Some serious problems are inherent with this approach. The interpreters may be able to do a good job with the imagery, but they may have little if any control over mission design and procurement. Such mission control may well be the most important aspect of the whole process. Noncentralized laboratories usually do not promote the use of remote sensing in the rest of the organization. An advantage, however, is that studies are limited to the specific functional unit, thus limiting personnel conflicts. This type of operation usually is not set up to do much research or to sponsor extensive improvements. It also fosters duplication of equipment, operation, and effort. For example, a good remote-sensing laboratory that operates in planning probably will not be fully used by other units, such as location and design, because of distractions caused by factors such as personal ambition, differences in modes of operation, lack of communication and understanding, and refusal or inability to provide the service needed. Although organizational management and supervision are the keys to all operations, the willingness to provide quality service, to cooperate, and to seek out those needing the service are also important factors.

Figure 2. Organizational structure of full-service remote-sensing laboratory within an aerial surveys and photogrammetric unit.



A remote-sensing laboratory can be under the jurisdiction of a specific unit but housed separately. It also can be established as a complete and separate unit. These alternatives also have their advantages and disadvantages. The greatest disadvantage of being housed separately is probably not having access to the peripheral equipment such as computer graphics and plotting equipment. By being a separate unit, acquisition of imagery may not be as expedient as it would be if the laboratory was attached to the aerial surveys unit, since requests to schedule missions may be placed on a waiting list and missions may rarely be combined. Missions designed for night flights and under adverse conditions may be refused. Pilots not trained for precise night flying may balk at such missions. Aerial photographers may also balk at using color infrared film because of the additional care needed in handling and exposing the film. Without a good service group, the addition of special equipment such as thermal scanners, radar, and multispectral scanners would not be effective. Although currently it may be far more economical to obtain this kind of imagery by contracting with private agencies, some equipment is inexpensive and should be housed in the unit.

Another way to handle remote-sensing needs is to rely entirely on private contractors. Problems with this method are difficulties in properly designing missions, in providing necessary controls, and in finding the needed expertise in required fields such as archaeology or pavement analysis. In order to get satisfactory results with this method, the relation between the private company and the transportation department must be very close, and the capability of the private company must not be exceeded. One advantage is that the company is used only when needed. Although the cost for an individual project may be high, the annual cost, as compared with an in-house operation, may be much lower. Some private companies also provide dependable and excellent interpretation services. On the other hand, few private companies have full remote-sensing capabilities, a fact that creates some problems. Even fewer private companies with full capabilities will be located near the study area. Increasing future demands may bring about an influx in the field of more dependable private companies. As this is accomplished, contracting to these companies may offer an attractive alternative to an in-house operation.

Five possibilities were mentioned above for housing a remote-sensing laboratory:

1. As part of the aerial surveys and photogrammetry unit,
2. As part of some unit such as planning or location that has considerable need for the laboratory,
3. In one or more units that have remote-sensing capabilities sufficient to satisfy their own particular needs,
4. In a totally separate unit, and
5. Through private companies by contract.

Based on our observations, the most effective remote-sensing operations appear to be those housed within aerial surveys and photogrammetry units. In addition, the most effective units provided service to many public agencies that reimbursed the laboratory for services rendered. Because the transportation department had responsibility for the laboratory in this case, it also had priority of service. A tentative organizational chart for the first alternative discussed is shown in Figure 2. Charts can be developed easily for the other alternatives. A fully operational remote-sensing laboratory can probably serve the needs of many state agencies in addition to the transportation department, such as surface mining, conservation, water resources, and wildlife resource agencies.

LEVEL OF SERVICE

When the establishment of a remote-sensing laboratory is being considered, some decisions must be made regarding the range and quality of service to be provided. The range and quality of service will depend on the equipment available, staffing and staff expertise, and interaction with all other units. The level-of-service concept is one of many possible approaches and probably can be demonstrated best by discussing some examples.

Full Service

Full service infers that the remote-sensing laboratory must be able to obtain the proper imagery, design the flight missions, provide full interpretive capability in all areas, and produce reports, maps, overlays, photographs, and any other needed graphics. Full service requires an extensive equipment layout, access to computer graphics equipment, printing and reproduction capability, and the ability to acquire the necessary types of imagery, including radar, satellite, and black-and-white photography. The most important element of the full-service approach is the ability to sit down with those who need the service and to take the time to work out all the details necessary for planning the mission: determine the kinds of imagery needed, the exact purpose of the project, and the exact form the output should take; set a time schedule for all efforts; allocate time and costs; and determine the detail to be included in the final report. These are crucial issues that must be worked out prior to initiating the study. Good estimates are needed, especially those that relate to study costs. The professional staff must be well trained, qualified, and respected. They should and must follow through on every project to the extent that they question the adequacy of the data gathered to meet the study's objectives, and they must determine if improvements can be made. This staff must be available for consultation by the users after the reports are completed. This type of operation becomes invaluable to the user.

Medium Level of Service

A medium level of service would probably constitute a resource commitment of equipment and personnel sufficient to provide well thought out and planned missions, good interpretation, a contract specification capability for color infrared photography and thermal infrared imagery, and personnel qualified in some of the disciplines that use remote sensing most. A well-qualified individual with a good general background in the use of remote sensing would be invaluable in training and assisting others in the use, analysis, and interpretation of imagery. At this level, more generalized prepared reports might accompany the package of imagery obtained for the requesting unit. A considerable amount of analysis and interpretation would still be left to the user. Only the key features would be delineated on the imagery and explained in the report. For this level of service, stereoscopes, zoomscopes, and other low-cost items of equipment needed to assist in visual interpretation must be available. Density-slicing equipment with color-coding capability may be helpful; however, due to its expense, it should be acquired only if the need for it can be justified.

Partial Level of Service

The partial-service concept may result in a remote-sensing laboratory being severely limited in the type of imagery it can provide, in the equipment it can acquire, and in the personnel it can employ. The remote-sensing laboratory may be limited, for instance, to obtaining only photographic imagery, i.e., panchromatic black and white, ektachrome color, black and white infrared, and color infrared. These types of imagery can be provided in-house by most standard aerial surveys units, although some aerial surveys units, for various reasons, strongly resist providing anything other than black-and-white aerial photography. Other types of imagery may be obtained through private companies, many of which are capable of meeting most imagery requirements.

Various types of imagery can be obtained from other agencies such as the EROS Data Center and the Tennessee Valley Authority. If the service to be provided includes evaluation and analysis of high-altitude and satellite imagery obtained from federal agencies, then the laboratory must be able to determine what types of imagery are available, the scale, dates of coverage, how much it will cost, and when it can be obtained. Some agencies, such as the EROS Data Center, provide automated interpretative assistance on a cooperative project basis. Other agencies, such as the Tennessee Valley Authority and the U.S. Department of Energy, obtain imagery of various kinds, such as thermal infrared imagery, for specific purposes. Such imagery may also serve the needs of the remote-sensing laboratory. Often a remote-sensing laboratory that provides only partial service can extend its service quantity considerably by taking advantage of the low-cost services provided by various outside agencies. Some private-sector companies, such as Texas Instruments and Mark Hurd Aerial Surveys, Inc., may have various types of imagery that, if satisfactory for the stated purpose, may be acquired at reduced rates. This also may be a way of extending the service level considerably at little extra cost.

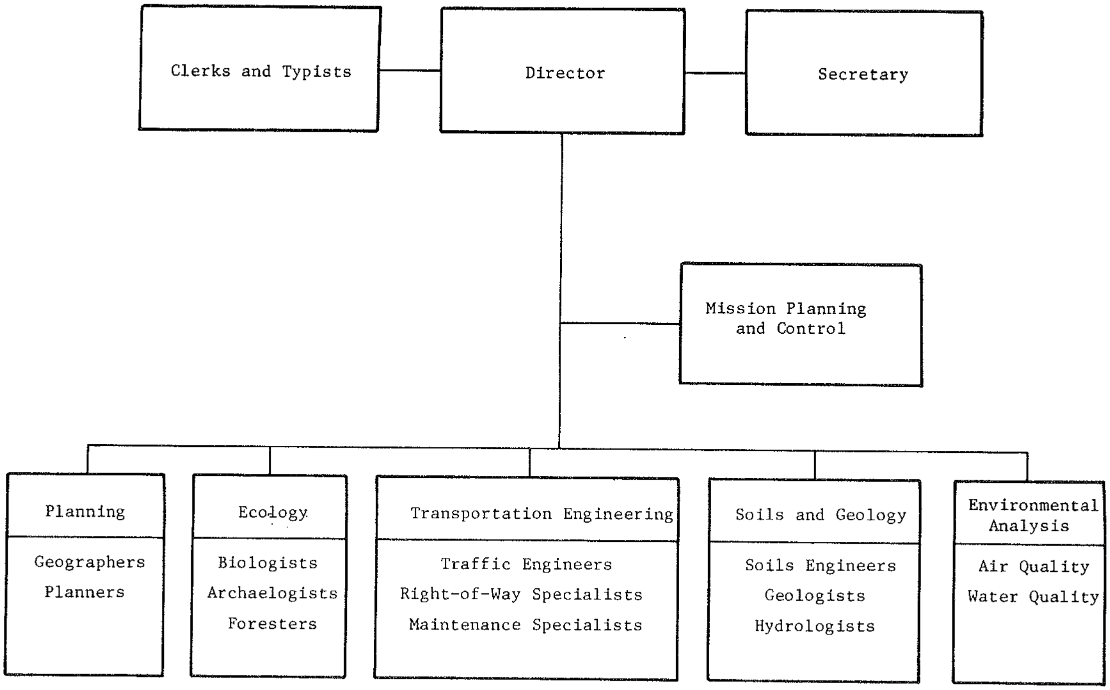
Low Level of Service

The lowest level of service for a remote-sensing laboratory would consist of providing only imagery, probably as a function of the aerial surveys and photogrammetry unit. Sometimes, this may include contracting for certain kinds of imagery, such as thermal infrared and radar. It may also include acquiring available imagery from other agencies and sources. This service level would not include interpretation, analysis, enhancement, or reporting. The lack of expertise for mission planning for the more sophisticated imagery may result in study failure. The flight mission for the purpose of obtaining thermal imagery, for instance, must be carefully timed to coincide with proper surface conditions. Only experts can design such missions. At this level of service, the studies that may be done are limited.

Influence of Personnel

Personnel are the key to the level of service that can be provided. At full service, staff personnel must be qualified in specific areas, such as archaeology, geology, biology, and forestry. These professional employees must be experts in their fields as well as in the use of remote sensing. They must also be able to design the mission, determine the types of imagery needed, use all available equipment in the interpretation process, perform data analyses, and prepare reports that are accurate and comprehendable. From this full-service level, the laboratory may be scaled down to the point that no professional employees are included on the staff in the various disciplinary areas and the laboratory provides only assistance in designing the mission and obtaining imagery. Generally, under the latter setup, the person requesting the imagery must know what type of imagery is needed and the conditions under which the mission should be flown. This setup may not be very effective, and it requires that the unit that uses the remote-sensing imagery have qualified interpreters. When more than one unit needs remote-sensing capabilities, duplication of equipment and manpower results.

Figure 3. Proposed tentative staffing plan for remote-sensing laboratory.



<u>Influence of Equipment</u>

Equipment available to assist the interpreter is rather extensive, and a fully equipped remote-sensing laboratory can cost millions of dollars, even when computer services and computer graphics capabilities are available from other groups. The full-service laboratory will probably contain such equipment as zoomscopes, density slicers, color-additive viewing equipment, an array of photographic equipment, magnification capability, and other automated and assisted visual interpretation equipment. Equipment available for analysis and interpretation affects the level of service that can be provided in a manner similar to the influence of personnel. If equipment is not available at a central location, the user must provide all equipment, even small hand lenses and pocket stereoscopes. Most remote-sensing laboratories will probably provide equipment at some intermediate level. Density-slicing equipment is fairly expensive but quite useful. Such equipment may best be housed at one location and made available to all qualified users. It may be practical to have the operation of analytical equipment assisted by one trained individual and the interpretation conducted by experts from the functional area that the study addresses to ensure accuracy. Usually, the more sophisticated the equipment, the greater the need for highly trained operators.

PERSONNEL REQUIREMENTS

Stringent personnel requirements are necessary for the professional employees, including the director of a remote-sensing laboratory. As illustrated in Figure 3, a full-service laboratory should employ a number of professional employees with good educational backgrounds in specific disciplinary areas. They should be well qualified through education and experience in the use and interpretation of remote-sensing imagery as applied specifically to their disciplinary areas. These positions should include, as a minimum, personnel with expertise in soils, geology, hydrology, geography, planning, ecology, biology, forestry, botany, archaeology, and transportation engineering. These employees should have rather broad backgrounds. For instance, the transportation engineer will be responsible for applying remote-sensing techniques to traffic engineering, maintenance, right-of-way, etc.

Under this setup, usually only one qualified individual, possibly with an assistant, will handle a specific area. In soils and geology, a soils engineer or a geologist may have to handle the entire area. In the ecology area, however, biologists and foresters are so different that both may be necessary. In the transportation-engineering area, a transportation specialist or someone with a broad general education and experience background may suffice, provided that this person works very closely with other units that need the services of the remote-sensing laboratory such as traffic engineering. The development of an effective laboratory is greatly dependent on obtaining a professional staff with good backgrounds in the use of remote sensing and in the interpretation of imagery. The laboratory should be set up so that it will be flexible enough to do studies in many broad areas, but yet restricted sufficiently, for example, to avoid letting biologists conduct traffic-engineering studies. The laboratory should provide a service and should not consider itself as being the final authority in any area. These laboratories should work with, support, and assist the units that have the responsibility for and specialize in a specific functional activity.

The director must be proficient in the management and operation of a remote-sensing laboratory. This individual must know about the various types of available imagery, instruments, and equipment; be familiar with interpretation methods and procedures; be proficient in mission design and control; be knowledgeable about photogrammetry and aerial surveys; have a good knowledge of photography and photographic laboratory procedures; and have good supervisory and managerial skills. It would be beneficial if this person were versed in the application of remote sensing in transportation, but few such individuals are available. The experience base of the director must be broad and must include positions of responsibility for problem solving, preferably in the role of team leader. Such individuals may have gained most of their experience in governmental agencies such as the National Aeronautics and Space Administration or military intelligence, in research at universities, or in private industry at such companies as Jet Propulsion Laboratory, Inc., and McDonnell-Douglas Aircraft Company. Work experience at more than one agency would also be an advantage to consider.

Personnel requirements will be predicated on the type of laboratory needed and by the type and level of operation envisioned. Overstaffing is probably worse than understaffing. Yet, adequate staffing of qualified personnel generates reliability and dependability. Unqualified personnel should not be hired, since the adverse effect on such a unit could be severe. Time and resources should be allocated for personnel training, which includes seminars, short courses, professional activity in the given discipline, and on-the-job training. Professional growth and development and peer recognition are especially important and should be provided. Dead-end positions cause serious problems and discontent and should be avoided if at all possible through the provision of promotional grades and eventually movement out of the remote-sensing laboratory into areas with more advancement potential. A progressive influx of personnel is essential to the generation of new ideas, creativity, and progress.

The management concept should encompass managerial and supervisory techniques necessary to operate a service-type organization and should be especially sensitive to restraints that control the operation. Management by objectives is one example of an effective management process and requires the development of realistic goals and objectives for the laboratory. The overall goals should be broad enough to encompass new methods, approaches, and developments. Goals should be receptive to change and include objectives that are realistic and flexible.

A remote-sensing laboratory must operate within a budget that could be expanded or reduced on an annual basis. This represents a definite restraint that must be recognized if a smooth, orderly operation is to be realized. Restrictions on the number and sometimes quality of personnel are also representative of restraints that can be imposed externally but that should not be permitted to unduly hamper the operation. Some trade-offs will always have to be made, and the goals and objectives should recognize and accept this reality. For instance, decisions often will be whether to acquire a piece of equipment, hire a needed professional, or postpone both for a year or indefinitely.

Table 1 lists the minimal needed staff, general qualifications, and estimated salary ranges. Salary ranges can be adjusted by a department's personnel section.

EQUIPMENT REQUIREMENTS

The equipment listed in Table 2 will be required for a full-service remote-sensing laboratory. For laboratories with less than full-service capabilities, the equipment should be chosen on the basis of expected study needs and on the qualifications of the professional staff. This applies to the more sophisticated equipment such as thermal scanners and density slicers. Most of the equipment listed under the first three categories in Table 2 is considered essential. This list is promulgated on the supposition that a full aerial surveys and photogrammetry unit exists or that this work is contracted for through the private sector and is available to the remote-sensing laboratory. Although a remote-sensing laboratory can function without access to computer terminals and computer-graphics capabilities, the availability of such equipment extends the laboratory's overall capability. Computer equipment is not itemized in Table 2 because, ordinarily, such equipment is on a time-lease basis, is centralized, or primarily serves another purpose. There are, however, circumstances that would necessitate the acquisition of a computer for the remote-sensing laboratory. The goals and objectives of the laboratory should be well established before considering the acquisition of a computer. An up-to-date cost estimate for equipping a remote-sensing laboratory can be accomplished quickly by referring to Table 2 and by consulting suppliers, many of whom advertise in such publications as Photogrammetric Engineering and Remote Sensing (published by the American Society of Photogrammetry, Falls Church, Virginia).

REMOTE SENSING THROUGH THE PRIVATE SECTOR

A number of firms in the private sector are set up to provide partial or full remote-sensing services, including radar and thermal scanning. Some of these firms are truly expert and have excellent interpretive capabilities, yet they do not totally substitute for a full in-house remote-sensing laboratory. For instance, it is difficult for private firms to maintain a full-time staff of individuals with expertise in the many areas addressed by a transportation department. The principal disadvantage of going to private firms is the difficulty in properly planning and designing the mission. The transportation department must prepare a set of rigid specifications, which means that it must have on hand at least one person well versed in remote sensing. Another disadvantage is that, due to contracting policies of most public agencies, consultant capabilities and department needs are difficult to realize fully or use. However, over the long run, contracting through the private sector may be the most economical approach. A fully organized company can provide service immediately, but a newly organized remote-sensing laboratory may not be fully operational for from a few months to a few years after being instituted.

For full effectiveness, a private company chosen to provide remote-sensing services should have full capability, have competent and well-qualified employees, be accessible, have good equipment, be reliable and dependable, and be able to work very closely with employees of the department of transportation. A possible approach may be to select a firm to provide services for a three- to five-year period. Such a company may be chosen on the basis of proposals submitted in response to a formal request that sets out specifications for quality, types of imagery that will be required, etc. Quantities to be delivered may be on demand within a limited schedule. A costing method will have to be devised that contains proper escalating clauses in order to protect the profit incentive of the private company. There seems to be a tendency among some transportation departments to be more stringent and more demanding of private companies than of their own organizations. Such an attitude is self-defeating and in the end will result in a lower quality of service.

RESEARCH CONSIDERATIONS

Research should be an important element of any well-

Table 1. Personnel requirements.

Personnel	Qualification	Estimated Annual Salary Range ($)
Director[a]	Expert in entire area of remote sensing is preferred; almost any disciplinary area is acceptable, but a generalist with a broad range of education and experience is best	30 000–40 000
Transportation specialists[a]	Should be transportation engineers with knowledge of structures, traffic engineering, maintenance, etc.	18 000–25 000
Soils and geology specialist[a]	Either a soils engineer or geologist may be used; individual should have some education and/or training in listed areas not represented by degree area and a knowledge of hydrology	18 000–25 000
Forester[a]	General background is probably best, since most have good educational backgrounds in wildlife, vegetation studies, resource management techniques, and statistics	16 000–25 000
Archaeologist[a]	Education in archaeology, anthropology, and historical documentation is necessary	14 000–20 000
Biologist[a]	General biologist with knowledge of aquatic life, mammals, and birds is needed; fisheries and wildlife majors will fit this description also	14 000–20 000
Geographer-planner[a]	Geographer-type planner may best fit the needs of this position because of more general background, which should include urban, rural, and transportation planning and especially the application of remote sensing	14 000–20 000
Secretary	Qualifications should be general, but individual must be able to adapt to use of technical terminology in many diversified areas; technical reports will be a major duty in addition to standard secretarial work	8 000–12 000
Clerks and typists	Typists should have ability to produce quality technical reports	7 000– 9 000
Editor	A background and education in journalism and/or English are preferred; individual must be able to handle technical writing; this is a valuable and useful position and must be staffed with a competent person	12 000–15 000

Note: The pilot who flies special missions may be assigned to the remote-sensing laboratory. If so, this person should have responsibility for assistance in mission planning and design but not the authority to dictate policy beyond personal safety. The aerial photographer or remote-sensing aerial equipment operator may or may not be assigned to the remote-sensing laboratory. If these persons are assigned to the laboratory, then they should be included in the list above.
[a]Professional.

Table 2. Equipment list and estimated cost.

Item	1981 Estimated Cost ($)
Adequate lighting (nonglare) within room and on images	
Simple general-use instruments to assist visual interpretation and analysis	
Magnifying glasses	
5 x large	15
10 x small	25
Pocket stereoscopes	20
Light tables (with even lighting)	150
Light tables with automatic film advance and retract mechanism	1000
Mirror stereoscope with magnification	1000
Planimeters, plain	250
Planimeters with digital readout	600
Dot grid for calculating areas	5
Overhead viewer (for transparencies)	500
Opaque projector with light curtain	1500
Sophisticated general-use instruments to assist visual interpretation and analysis	
Stereo zoomscope for cut or single frame transparency viewing	9000
Bausch & Lomb 95 zoom stereoscope or equivalent for viewing uncut roll film	5000
Specific-use instruments to obtain and analyze thermal imagery	
Thermal scanner (on-board mounted with magnetic tape) (Daedalus)	300 000
Thermal scanner with on-board analog computer analyzer (Daedalus)	700 000
Portable low resolution thermal scanners (AGA or Inframetrics, Inc.)	85 000
Density slicer with color coder, television camera and stand, analog computer, cursor or pointer control, and cathode ray tube (CRT) (color)	15 000
Polaroid camera and hood for use with density slicer	1000
Direct color hard copier (Dunn Instruments or equal)	12 000
Instruments to density slice and color code black-and-white imagery (same as specific-use instruments listed above)	
Landsat satellite imagery interpretation and analysis	
Interpretation of Landsat imagery, when obtained in the form of photographs, may be accomplished with the types of instruments listed here and under the heading of simple general-use instruments	
Landsat data tape reader with enhancement and data classification capability, output on CRT with hard-copy prints provided by Dunn Instruments or equal	105 000
Color-additive viewer for analysis of Landsat imagery (not recommended for acquisition unless it can be obtained from government surplus and reconditioned for a total cost of less than $1000)	1000
Radar imagery	
In siting dams and bridges and in locating highways, available radar imagery should be ordered; analysis of such imagery only necessitates the use of inexpensive types of equipment as listed under general-use instruments	
When coverage is not available, contracting for radar imagery is advised rather than purchase of radar equipment	
Radar equipment	500 000–1 000 000
Color infrared capability—cost over and above that required to produce black-and-white photography	
Additional film cost	-[a]
Film storage cost assumes refrigeration is currently used	None
Additional processing cost	-[b]
Digital analysis equipment	
Television camera, light table, flood lights, adjustable television camera mount, cursor control and video monitor	20 000
Digital-to-analog and analog-to-digital converter	15 000
Additional addressable memory	15 000
Minicomputer including tape and disk storage	50 000
Software (varies with complexity of analyses desired)	10 000–100 000
Active table, cursor, menu tablet	10 000

[a]Costs about three times that of black-and-white photography.
[b]Costs about two-and-a-half times that of black-and-white photography.

functioning unit. This is especially true for a remote-sensing laboratory because of the continuous advances in automated interpretation, analysis techniques, new films, computer applications, etc. Research in new application areas is essential for a viable laboratory. New ideas, techniques, and methods should be explored and used as soon as a reasonable degree of confidence is obtained. Of course, research should not be permitted to interfere with operations, nor should production reliability be sacrificed. A reasonable range of effort and commitment of resources to research is probably between 10 and 20 percent, with some reasonable degree of flexibility between research and production. Pure or basic research, in most cases, should be relegated to the higher educational institutions, but applied research is appropriate and probably essential. An example would be studies on the use of thermal scanners for detecting moisture under pavements. It is probably not appropriate for such a unit to commit more than 20 percent of its resources to research. Above this commitment, one must ask what benefits accrue to the operational units. Research is, however, necessary for progress, generation of new ideas, and creativity. Occasional new personnel and research are necessary ingredients for change and progress and for helping to prevent stagnation.

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