Institutional Issues Affecting the Integration and Use of Remotely Sensed Data and Geographic Information Systems

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ABSTRACT: The developers as well as the users of remotely sensed data and geographic information system (GIS) techniques are associated with nearly all types of institutions in government, industry, and academia. Individuals in these various institutions often find the barriers to accepting remote sensing and GIS are not necessarily technical in nature, but can be attributed to the institutions themselves. Several major institutional issues that affect the technologies of remote sensing and GIS are data availability, data marketing and costs, equipment availability and costs, standards and practices, education and training, and organizational infrastructures. Not only are problems associated with these issues identified, but needs and opportunities also are discussed. An agenda of suggested research topics is presented that relates to problems associated with data, equipment, standards, education/training, and organization structures. With a greater focus of research on institutional issues, the understanding, integration, and use of remote sensing and GIS technologies could be enhanced.

INTRODUCTION

REMOTE SENSING IS A SOMEWHAT UNIQUE TECHNOLOGY in that its transfer to users has been conditioned not only by the U.S. Federal role, but also by governmental agencies around the world. Geographic information system (GIS) technology, while not as tied to federal-level institutional constraints in its development, has nonetheless been influenced by the needs of the Federal establishment and the needs of local to international governmental agencies. Integration of remotely sensed data with GIS's has been, and indeed continues to be, subject to a variety of institutional as well as technical limitations (Estes, 1981). Colwell (1987) referred to institutional issues as "deterrents" that often create barriers to the adoption of modern remote sensing technology. He identified these deterrents as overselling, overkilling, undertraining, underinvolvement, spurious evaluation, misapplication, timidity (sometimes known as gutlessness), inadequate infrastructure, inadequate understanding, and inordinate distrust.

In this paper six institutional issues affecting the use of integrated remote sensing and GIS technologies are addressed: (1) data availability, (2) data marketing and costs, (3) equipment availability and costs, (4) standards and practices, (5) education and training, and (6) organizational infrastructures. These issues and subsequent suggested research topics are not intended to be exhaustive, but are presented to stimulate ideas and discussion and generate opportunities for research on procedures to eliminate, or at least minimize, institutional impediments to a better integration of remote sensing and GIS technologies.

BACKGROUND

Extraordinary advancements have been made in recent years in the technical fields of remote sensing and GIS technologies. These advancements can be attributed to the deployment of new satellite sensor systems, the construction of large-area databases, the merging of image and cartographic data sets, and the development of innovative modeling algorithms for spatial analysis. The rate of development of remote sensing and GIS technologies, however, has been much faster than the understanding, acceptance, and use of these technologies in an institutional context.

Strome and Lauer (1977) reported on a study by Battelle Columbus Laboratories that found technologically advanced societies are unable to transform quickly new ideas into successful products. According to the Battelle study, the timeframe from year of conception to year of realization for the heart pacemaker, hybrid corn, and the oral contraceptive was 32 years, 25 years, and 9 years, respectively. The average timeframe for ten innovations studied was 19.2 years. The process of technology acceptance in any field is complex, and research results often require decades to achieve practical application. In the case of remote sensing and GIS technologies, the process is even more complex because the users are affiliated with so many different types of institutions—government (Federal, State, local), industry (corporations, small businesses, private consultants), and academia (universities, colleges, institutes, consortia). The land managers, resource specialists, or environmental scientists in these institutions find that the barriers to accepting remote sensing and GIS, either separately or as an integrated technology, are not always technical, but rather can be attributed to the institutions themselves. Thus, a better understanding of institutional issues might lead to their mitigation and to improved success in the integration and operational uses of remote sensing and GIS technologies.

Further complicating remote sensing and GIS integration are issues related to interdisciplinary barriers. Engineers often have difficulty communicating with environmental scientists. Environmental scientists have difficulty communicating with computer scientists, who have difficulty communicating with public officials, and so on. Although there are individuals who can successfully communicate across disciplines, there are simply not enough people with this special talent. Education is one

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key, but another is the realization that information transfer gaps do exist and conscientious efforts must be made to close these gaps.

INSTITUTIONAL ISSUES

DATA AVAILABILITY

Hard-to-Find Data. A common complaint among users of remotely sensed and other forms of digital spatial data is that they have a difficult time finding out what data sets are available. There are few catalogs available that describe digital cartographic data sets and their attributes. The Federal Interagency Coordinating Committee on Digital Cartography (FICCDC), recently renamed the Federal Geographic Data Committee, has noted that most digital data sets are created for a particular purpose or to support a particular program (FICCDC, 1990). In the remote sensing and GIS fields, the creation and use of data sets often occur within the same program. Consequently, in most cases there is no program-related need to advertise the availability of the data set. For a data set to be available to potential users, the original program requires a marketing effort that includes a distribution mechanism and an institutional commitment to furnish the data in formats and on media that may not have been required by the original program. This additional effort requires an institutional commitment to an ongoing service program to help users decide if the data set is usable for their purpose. It requires an institutional willingness to consider the needs of users and to modify standard products to meet those needs. These service efforts require resources that are usually not included in the original program. The required resources may represent only marginal increases in the base program, yet the investment is usually not made. Only the largest programs in digital cartography, such as those conducted by the U.S. Geological Survey (USGS) and the Bureau of Census, currently provide an adequate product awareness activity.

It is important to note that many of the problems noted here are recognized and that the Office of Management and Budget (OMB) recently released a revised Circular No. A-16 to improve coordination of surveying, mapping, and related spatial data activities (OMB, 1990). The intent of this coordinated effort is to develop a national digital spatial information resource, build partnerships, avoid duplication, and encourage sharing among government institutions and the public and private sectors. Participating Federal agencies will be seeking OMB support as they jointly establish and develop a National Geographic Data System.

Nonexistent Data. Jensen *et al*. (1989) have identified certain critical remote sensor systems and data types that currently are not available but would be helpful for integrating remote sensing and GIS technologies. They note, for example, that (1) there are no 1- by 1-m to 5- by 5-m spatial resolution data from space sufficient to meet many of the urban mapping requirements, particularly in developing nations; and (2) there will be no remotely sensed data of any kind collected systematically for tropical regions of the world until a synthetic aperture radar system is placed in orbit. Therefore, very little can be done in the integration of remote sensing and GIS technologies for tropical regions of the world. These two examples are representative of the problem of nonexistent data. Further study is required among interested institutions to determine the most cost-effective and efficient means of acquiring these nonexistent data. Future space systems planned by the European Space Agency, Japan, the U.S.S.R., and the U.S., or the careful planning of aircraft missions, could possibly meet the need.

Data Sharing. The FICCDC's User Applications Working Group has reported that unrealized potential exists for much greater sharing of federally produced digital spatial data (FICCDC, 1990). Cooperative actions (i.e., sharing) are happening, but there is considerable room for improvement. There are many reported examples of different agencies independently collecting or digitizing the same data sets. One goal of the FICCDC was to reduce duplicative digitizing efforts. It was assumed that one reason duplication of effort among different organizations occurred was because the parties were not aware that they both were doing the same thing. But when the degree of awareness was increased, mainly through the efforts of the FICCDC and the OMB Circular A-16 process, the situation persisted, which would indicate that additional barriers to data sharing must exist. The FICCDC's User Applications Working Group is attempting to identify these barriers. The Working Group suggests that the barriers can be classified as either technical or institutional. Technical barriers concern the content, quality, and structure of a data set. They include the questions of media, format, and encoding, factors that must be considered by a receiving party before it can read and understand a digital data set.

Institutional barriers concern an organization's resistance to sharing data. Producing agencies may fail to put data into a form that can be widely used. Users are often unaware of the existence of potentially useful products. Users often prefer to digitize data from maps rather than share another party's digital data set, and some data producers retain a proprietary interest in data. Proprietary considerations often apply to data collected from private companies by the Federal Government. Some organizations are reluctant to announce digital products while others are reluctant to order such products because of the unceratin status of the liability for accuracy of the data.

DATA MARKETING AND COSTS

Geographic and Cartographic Data. The FICCDC Working Group also noted that, for a GIS manager, it may be more cost effective, or at least more expedient, to digitize data from maps than to search for and assess suitable existing digital cartographic data sets. However, if a Federal agency establishes a product awareness program, such as has been done by the USGS for its National Digital Cartographic Data Base, then the search can be done quickly and at minimal cost to the user. This is essentially the thrust of the work being done by the National Aeronautics and Space Administration (NASA) on the Master Data Directory at the National Space Science Data Center. This work is considered by many participants in NASA's Earth Observing Systems (EOS) program to be critical in ensuring effective use of EOS data for global change studies. Nevertheless, many organizations that produce digital cartographic data fail to take the extra steps necessary to establish a product awareness and marketing activity. From the viewpoint of local program managers, these activities are not part of their program responsibilities and, in times of tight budgets, they cannot afford to allocate resources to them. In such cases, there may be a reluctance to go beyond the objectives of the original program and make marginal investments to serve the common good. The extra steps, and the ensuing benefits for the cartographic and GIS community, are not likely to occur unless institutions accept the responsibility or are provided some incentive for marketing their digital cartographic data sets.

The revised OMB Circular A-16 process and the establishment and development of the National Geographic Data System are designed to encourage data sharing. Participating Federal agencies, however, still must make an institutional commitment to share data which will require not only OMB support, but also a change in attitude by most program managers.

Satellite Remotely Sensed Data. Data marketing strategies and costs for satellite remotely sensed data are considerably different from the costs associated with capture and distribution of digital cartographic data. In this case, the U.S. Government has transferred the civil Landsat program to the private sector with the expectation that the program can be managed and operated on a commercial basis (U.S. Department of Commerce, 1980).

The premise for commercializing the Landsat program was that, in a reasonable amount of time, revenues would exceed costs, Government subsidies would be eliminated, and a profitable commercial enterprise would fluorish. Because revenues are to date a fraction of total program costs, heated debates occur among the various institutions over appropriate Landsat product prices and the wisdom of commercializing the program. Early in the program, the USGS set product prices according to the Department of the Interior's (DOI) legislative guidelines in which prices were based on the cost of reproducing the archived product and not on the high costs of acquiring raw data. Thus, in the 1970s, satellite photographic images were priced between $8 and $50, a digital multispectral scanner (MSS) tape cost $200, and annual revenues were approximately $3 million (Pohl and Smith, 1979). As National Oceanic and Atmospheric Administration (NOAA) planned for an operational system, it hypothesized that a fivefold to tenfold product price increase would easily cover ground handling costs and would increase annual revenues over time to $30 to $40 million (U.S. Department of Commerce, 1980). NOAA further hypothesized that a 10 percent growth in sales a year plus a fivefold increase in both product prices and foreign station data reception fees would generate annual revenues of $140 million by the year 2000.

Thus, in concert with the commercialization thrust, overall Landsat data prices have been increased first by NOAA, then by the Earth Observation Satellite (EOSAT) Company, the commercial operator (Table 1). Since 1980, prices of MSS and thematic mapper (TM) photographic products have increased 1,000 to 2,000 percent and MSS digital tapes 500 percent. TM digital tapes have increased in price almost 200 percent. The price history of Landsat data sales in the United States is shown in Table 2. Not surprisingly, as data prices increased, users became more selective of what they purchased and units sold decreased (R. A. Pohl, unpublished material, 1988; A. H. Watkins, unpublished material, 1989). In fiscal year 1976, the USGS's EROS Data Center shipped almost 300,000 frames of Landsat photographic imagery (Austin and Rothenbuehler, 1989). Shipped frames dropped to about 125,000 in 1980, to 40,000 in 1985, and to less than 5,000 in 1989. The number of Landsat digital tapes shipped by the Data Center was about 3,000 in 1976, 4,000 in 1980, 6,500 in 1985, and more than 7,000 in 1989. (EOSAT also directly ships some photographic images and digital tapes from Lanham, Maryland, which are not included in these figures.) The drop in photographic images shipped from one year to the next is not surprising, because this has been the trend for several years. In the early 1980s, when photographic image prices averaged $15 to $20 an item, more than 100,000 items were shipped a year. For the 4,200 photographic images shipped in fiscal year 1989, the price range was from $90 to $1,000 an item. EOSAT attributes at least some of this loss of market share to the availability of data from government-subsidized foreign systems, such as the Satellite Pour l'Observation de la Terre (SPOT) and from sensors on U.S. Government's weather satellites, such as the Advanced Very High Resolution Radiometer (Foley, 1989). These trends also show that Landsat data are now being purchased primarily by only a few government agencies and a number of aggressive corporations. Research facilities, academic institutions, educators, students, State and local governments, and the governments of less developed nations are now purchasing considerably less data than they did a few years ago (Voute, 1987; W. C. Draeger, unpublished material, 1989).

In the opening session of the meeting of Directors of National Remote Sensing Centers, sponsored by the United Nations Development Program's Economic and Social Commission for Asia and the Pacific (ESCAP), in Shanghai, People's Republic of China, in July 1988, the Executive Secretary of ESCAP commented on the "...widespread concern about the increasing cost of obtaining remotely sensed data", and the need to "...explore the possibility of assisting member countries to obtain such data at more reasonable prices" (Kibria, 1988). Then, one director after another included a statement in his or her annual report that condemned current pricing policies for Landsat and SPOT data. For Indonesia, it was "...the unfavorable price relating to satellite imagery" (Irsyam, 1988); for Pakistan, "... the commercialization of satellite remote sensing systems and the increasing cost of space segment services could have an adverse effect on the development of remote sensing programs" (Mehmud and Mirza, 1988); and from Sri Lanka, "...paucity of funds has also limited the frequency with which air photography or satellite imagery could be obtained" (Berugoda, 1988). Even a recent report from People's Republic of China noted that, if the costs of satellite imagery continue to remain high, China and other countries in the region may have to abandon satellite remote sensing technology and return to the sole use of aerial photography (He, 1989).

Since the mid-1970s, the Regional Center for Services in Surveying, Mapping, and Remote Sensing in Nairobi, Kenya, has provided training, user assistance, and project support services to the national centers in east Africa. But, Hassan and Falconer

TABLE 1. LANDSAT PRODUCT PRICE EXAMPLES

		Photographic Images			
Year	Organ.	MSS B&W 10" Neg.	MSS Color 40" Print	TM B&W 10" Neg.	TM Color 40" Print
1980	USGS	$ 10	$ 50		
1982	NOAA	$ 35	$ 175	$ 35	$ 175
1985	NOAA	$ 40	$ 195	$ 80	$ 290
1985	EOSAT	$ 90	$ 350	$ 160	$ 500
1989	EOSAT	$ 90	$ 550	$ 300	$ 800
1990	EOSAT	$ 175	$1,000	$ 500	$1,500
		Digital Tapes			
Year	Organ.	MSS/CTT	MSS Acq. Fee	TM/CCT	TM Acq. Fee
1980	USGS	$ 200			
1982	NOAA	$ 650	$ 790	$2,800	
1985	NOAA	$ 730	$1,120	$4,400	$1,600
1985	EOSAT	$ 660	$1,120	$3,300	$1,600
1989	EOSAT	$ 660		$3,600	
1990	EOSAT	$1,000		$3,960	

Sources: U.S. Geological Survey, National Oceanic and Atmospheric Administration, and EOSAT Company.

TABLE 2. LANDSAT DATA SALES AND PRICE HISTORY

Year	Film Items Sold	Average Film Price	CCT Items Sold	Average CCT Price
1980	128,433	$ 15	4,139	$ 200
1981	128,755	$ 15	4,351	$ 200
1982	115,025	$ 20	4,974	$ 250
1983	76,621	$ 30	5,599	$ 500
1984	34,964	$ 60	5,042	$ 500
1985	39,079	$ 60	6,704	$ 500
1986	19,061	$125	7,100	$1,000
1987	12,388	$150	7,842	$1,000
1988	9,088	$150	7,992	$1,000
1989	4,206	$150	7,374	$1,000

Source: A. H. Watkins, Landsat and SPOT Data Sales; U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota

(1987) reported that the computer tapes comprising one single Landsat TM scene cost the same in Africa as employing a competent car driver for four years. They also noted that, if a country purchases the tapes using precious foreign exchange reserves, multiple use of the data throughout the country or region is restricted by the condition of sale. Consequently, for the Nairobi Regional Center or for any other regional and national remote sensing center in less developed countries to obtain satellite data exhibiting information about the extent and condition of Earth resources in its region, that center must ask for support from institutions in the industrialized nations to acquire the data.

NOAA and EOSAT recently announced that Landsat MSS data more than two years old can be purchased without restrictions from the USGS's EROS Data Center for the cost of reproduction—an institutional agreement that partially alleviates the problems noted here.

Equipment Availability and Costs

To integrate remotely sensed data into a GIS, users must merge two sets of technology. Some of the equipment and procedures are common to both, but considerable additional hardware and software may be required. As users attempt to work from what they have to what they need, several problems may occur. While these problems are common, they are also chronic and can be difficult to overcome if not fully understood. Below are listed some of the most common institutional hardware/software pitfalls.

Limited Budget. All institutions place constraints on available budget. With a limited budget, an institution may be tempted to follow a course of action that involves acquiring hardware and software that can *demonstrate* GIS and remote sensing integration without having the capability (or capacity) to properly *conduct* project work. If pilot or demonstration projects employ different systems other than the targeted operational capability, the transition to an operational system can be difficult. The use of inadequate systems with flashy outputs may generate the needed support, but they can also waste considerable time and money when hardware, software, and training costs are calculated. The obvious solution is to make certain that the first system is not a "throw away" acquisition. For example, one possible approach is to use a workstation configuration for demonstrations, and then to augment that system with file servers, additional workstations, and shared output devices (e.g., plotters, film recorders) when an operational system has been justified. A basic understanding of system development methodologies also will alleviate many of the problems noted here.

Inadequate Support Staff. Software and hardware systems for digital processing of remotely sensed data will require more time and effort to support than most users acknowledge. On the other hand, technical support for operating system and applications programs, and engineering support for the specialized display and output devices, are critical. Even "turn-key" systems, while providing some efficiencies in the packaging of needed components, will require highly technical support and training at times. It is important that this support factor be considered in the initial decision-making process, especially by agencies that are geographically or institutionally isolated from good hardware support (e.g., developing countries).

Evolving Technologies. The technologies of remote sensing and GIS continue to progress rapidly, which is good news. Unfortunately, there are very few hardware/software configuration standards to guide new users. Also, the interfaces between a new system and other systems often lag far behind the development of analysis capabilities. One approach that has been taken by large, centralized institutions is to enforce a standard configuration. This approach has not always worked well because it tends to stop the evolutionary process at a point when the system requirements and technological limitations are not fully understood. A more prudent approach would be to concentrate on the interface technology and to promote data sharing as a means for encouraging mutually beneficial interchange of new technology.

Public Domain Software. One of the more subtle institutional pitfalls is the promise of a "free lunch"—public domain software. With limited budgets, many institutions spend money on the hardware components of a system, hoping that public domain software will provide adequate capabilities, at least in the short term. This approach seems quite logical for a phased implementation. If the software is inadequate, it can be replaced at some future time (and with future funding sources).

The public domain approach can and does work at times (Nyquist, 1987), but only if (1) the public domain software performs all necessary functions (as opposed to functions that are "nice to have"), and (2) the user can understand the software well enough to continue development until it performs adequately. This is not to say that public domain software is usually doomed to failure. The National Park Service and Soil Conservation Service, for example, have successfully established mechanisms for using public domain software.

The public domain approach will fail if institutions (and users) do not understand the fundamental nature of free software. Government-developed software is generally available on a "what you see is what you get" basis. Promises of future enhancements and improved user support should be viewed with skepticism because system developers will most likely be assigned to new developments or to support paying customers, rather than to improving software already released to the public domain.

Failure to make public domain software perform operationally is generally more costly than would be expected. There is the cost for replacement software, but also there is the time and effort spent in learning to use (and enhance) the software, and the time needed to relearn a new system. The point is that the "free lunch" approach is not for everyone. In fact, institutions should be very cautious in assuming that public domain software will solve their operational problems. Because similar statements often can be made about commercial software, all users should be cautioned about any software, public or private, when applied to operational problem solving.

Standards and Practices

Sources and magnitude of errors are major issues in the integration of remote sensing and GIS technologies. Inconsistency and error can creep into a study that incorporates remotely sensed data and GIS techniques when the analyst is not properly trained or uses improper methods. Much of this error may be removed or at least documented if the analyst uses professional standards and practices.

Remote sensing and GIS professionals do not need to be licensed or certified to practice. In 1977, the American Society for Photogrammetry and Remote Sensing initiated a voluntary certification program for photogrammetrists, including remote sensing specialists. As of September 1990, only 618 (7.7 percent) of the approximately 8,000 members of the society have become certified. The Society is also developing criteria for recertification. There is no certification program for GIS specialists as of September 1990, although the society is in the process of developing a GIS certification program (J. Shrader, personal communication, 1990). Therefore, almost anyone who has taken a short course in remote sensing or GIS technology may conduct research and report the results as if they were well qualified.

In addition to the vast majority of practitioners lacking certification, there are no defined standardized practices. Standard practices should be established for the use of remotely sensed data, such as for geometric registration and thematic classification. Similarly, like specifications for the preparation and use of digital cartographic data (NCDCDS, 1988), standardized practices should be established for the design and use of GISs. Standard practices might begin with the requirement that all analysis procedures be documented.

To prevent unqualified scientists from using nonstandard remote sensing and GIS practices, professional societies should take charge of the certification process and work to develop methodological standards and practices. Among the most logical societies are the American Society for Photogrammetry and Remote Sensing, the American Congress on Surveying and Mapping, and the Urban and Regional Information Systems Association. The National Center for Geographic Information and Analysis could also participate in developing GIS standards and practices. The professional standards and practices should be updated periodically to incorporate improvements in logic, technology, and computation methods. Improvements in standards and practices would make products derived from remote sensing and GIS analysis more consistent. The public then would have more confidence in products derived from remote sensing and GIS technologies.

Education and Training

The status and content of remote sensing and GIS education and training in the United States is poorly understood. Only a few studies have documented the status and content of the educational system and how it functions (Dahlberg and Jensen, 1986; Kiefer, 1988; Civco and Kiefer, 1990). Nevertheless, some general observations about institutional and programmatic shortcomings in the remote sensing/GIS educational system can be made.

Who Performs the Education and Training? Perhaps too often a faculty member is conscripted into teaching remote sensing or GIS subjects because they have had a single course in these areas and are, by default, the most literate on the subject within the department. Conversely, the ideal educational environment occurs with a professor who has a sound background in remote sensing and GIS technologies and is actively involved in remote sensing research. In certain instances, students may have the opportunity to work with the professor as research assistants. This interaction in a research environment educates students on how to approach and solve problems. Also, research ethics are communicated to students. Well-trained professors ensure that erroneous misconceptions about remote sensing and GIS technologies are not propagated and that inaccurate results are not produced when interpreting remotely sensed data.

Considerably fewer opportunities for assistance and training exist in less developed countries, where the infrastructure for making effective use of remote sensing and GIS technologies is often lacking. Part of the infrastructure needed in these countries is well-educated and highly trained personnel, which involves training decision makers and teachers and providing training materials (Tauch and Albertz, 1986). In the case of satellite remote sensing, it is not clear under the current U.S. policies guiding the commercialization of Landsat whether educational cooperation with less developed countries is a government, commercial operator, or joint government/commercial operator responsibility, or whether it is even considered an important institutional issue. What is clear, however, is that over the last few years there has been a significant decrease in U.S.-sponsored education and training programs for less developed countries in the uses of commercially available satellite data.

Training in Field Techniques. Most remote sensing courses do not include actual field work. Remote sensing courses in the future must teach students how to (1) conduct specific types of field sampling (e.g., soil moisture, leaf area index, biomass) that support and calibrate the remotely sensed data, (2) use (and especially how to calibrate) spectroradiometers to measure the terrain *in situ*, and (3) relate or model the *in situ* data with the remotely sensed data. Remote sensing courses also must improve the teaching of *in situ* data collection techniques, which build upon other field techniques learned in the student's systematic study area (e.g., soil measurement techniques). Training in field techniques is an area of great significance, which must be addressed.

Knowledge of Fundamental Principles. Students who take digital cartography or GIS courses without taking the introductory thematic cartography courses have a strong potential to produce misleading and often inaccurate cartographic results. Similar problems occur when students take digital image processing courses without ever having had a fundamental course in photointerpretation. It is imperative that a student progress from a knowledge of fundamental aerial photography, to more exotic sensor systems and then, and only then, to interpretation of images using digital image processing techniques.

The Analog Versus Digital Dichotomy. During the 1970s and early 1980s, substantial emphasis was placed on the development of digital image processing and digital GIS technology. At the same time, the science of photointerpretation remained relatively stagnant without much development of new theory and knowledge. New types of satellite data (especially SPOT 10- by 10-m panchromatic and enhanced TM data when available) often contain information similar to that available from panchromatic aerial photography. Therefore, a new synergistic relationship is developing. For rural, agricultural, and forestry areas, data analyzed by digital image processing techniques may yield the best results. Conversely, for urban areas and other environments that consist of high spatial frequency information, the data may be best analyzed by a human who may or may not use digital image processing techniques. Thus, the product that eventually ends up in a GIS database may be a mixture of both analog and digital image processing techniques (Jensen *et al.*, 1990). Visual photointerpretation techniques will become just as important as digital techniques. In fact, true expert systems in remote sensing capitalize on both visual and computer-assisted data anlyses (Jensen *et al.*, 1989). Those who know only digital image processing techniques will be severely handicapped as the higher spatial resolution remotely sensed data become available. Course offerings in visual image interpretation should take this future scenario into consideration.

Remotely Sensed Data Sets for Education and Training. Institutional issues have had an obvious negative impact in the areas of education and training. Studies have shown that users, especially potential users, of satellite data are generally not trained in how to make maximum use of these data (Maxwell, 1980; Henderson, 1986). Some of the problems in education and training were noted by Estes (1980) at a conference among remote sensing educators at Stanford University on 26-30 June 1978. He was tempted to call a well-trained remote sensing technologist a person who is "all things to all people" because of the breadth of physical, biological, and socioeconomic information embodied in the technology. Both user assistance and formal training opportunities related to satellite remote sensing are generally available in the United States and in most other developed countries (Estes *et al.*, 1980; Dahlberg and Jensen, 1981). One noticeable impact in this area, however, has been a decrease in the amount of Landsat data sold to colleges and universities. In 1976, customers in academia purchased from the USGS's EROS Data Center over 25,000 Landsat photographic images and 270 digital tapes for a total of $177,000 (W. C. Draeger, unpublished material, 1989). In 1988, they purchased only about 400 photographic images and 380 digital tapes for $330,000, a cost of approximately double the 1976 expenditure. Other factors besides data prices may have affected demand over this 12-

year period, but there is little doubt that large price increases have limited academia's access to Landsat data. Furthermore, there is very little sharing of satellite remotely sensed data because of copyright restrictions placed on data by SPOT Image and EOSAT. These companies have developed an initial image database of a limited number of scenes, which can be purchased at a nominal fee by academics (Barker, 1990; EOSAT, 1990). However, there needs to be a data bank set up for instructional purposes by the National Center for Geographic Information and Analysis or some other entity that collects and catalogs analog and digital images from around the world. Instructional remotely sensed data should be made available to the academic community for the cost of duplication.

A Remote Sensing Core Curriculum. Given these observations and recommendations, the establishment of an undergraduate remote sensing core curriculum would seem appropriate (Civco and Kiefer, 1990). This curriculum would be developed by representatives from academia, practicing resource managers, and professional societies. For example, the National Center for Geographic Information and Analysis is developing such a core curriculum for education and training in GIS. The first draft of the three-part program, consisting of an introduction to GIS, technical issues in GIS, and application issues in GIS, was completed in the summer of 1989 and has undergone extensive evaluation by educators during 1989-1990 (Estes *et al.*, 1990). The curriculum consists of a comprehensive set of lectures and laboratory exercises and is an attempt to standardize introductory, technical, and applied training in GIS. A similar core curriculum for remote sensing education is neded, perhaps using the GIS curriculum as a model. Civco and Kiefer (1990) suggest that a remote sensing core curriculum include (1) introductory remote sensing, (2) advanced remote sensing, and (3) case studies. Additional courses would be developed to support the core curriculum.

Organizational Infrastructures

As noted, institutional issues rather than technical factors usually govern the acceptance and use of remotely sensed data and GIS techniques. For an organization to use digital spatial data operationally, a viable infrastructure and a capacity for internal problem solving are essential. When the first Landsat was launched in 1972, there was no infrastructure in place for using satellite remote sensing in any of the Federal land management agencies. Therefore, there was little acceptance or understanding of Landsat technology and consequently, little use of the data. Over a 10-year period, the necessary organizational infrastructures were established – managers were made aware, equipment was purchased, demonstration projects were conducted, and resource specialists were trained. Federal agencies eventually integrated this new space technology into operational land management programs. In the Department of the Interior (DOI), for example, almost every bureau established a remote sensing coordinator and hired remote sensing experts. Today, the USGS's EROS Data Center acts as a central facility in support of the Department's national remote sensing program, and the Chief of the Data Center chairs the Department's Remote Sensing Task Force, a coordinating body for current and future remote sensing activities.

Long-Term Technical and Financial Commitment. A crucial ingredient in the Federal organizational infrastructure is the long-term technical and financial commitment to these new technologies by Federal agencies. Likewise, if digital spatial data are going to be accepted and used worldwide, a similar commitment must be made by participating government organizations. A U.S. program for international cooperation in remote sensing and GIS technologies must include long-term technical and financial commitments that will allow the establishment of institutional frameworks, organizational infrastructures, and needed human resources in developing regions of the world.

In one important respect, however, these institutional commitments need to be strengthened. More resources need to be directed toward fundamental research on remote sensing/GIS integration. A recent National Academy of Sciences report on "Spatial Data Needs: The Future of the National Mapping Program" states:

> If ours is to be an information-based economy that is competitive on a global basis, there is a critical need for a coordinated and efficient national information infrastructure to facilitate the sharing and communication of information resources (National Research Council, 1990).

One of the report's major recommendations is that the USGS's National Mapping Division should expand its current research activities in digital cartography, GIS's, remote sensing, and image processing. This recommendation applies equally to several other Federal agencies as well.

Moore (1987) suggests that a solution for gaining increased involvement of developing countries (in this case, in using remotely sensed data in a GIS for hydrologic studies) must include ensuring continued data availability to programs that train resource scientists and managers. He believes programs that financially support data purchases have a better chance of creating an information explosion in developing countries than the programs that do not provide the needed data. Moore also notes that, to use the information beneficially, integrated resource inventories, well-structured monitoring programs, and efficient information handling and management systems also must be established, which would require a major increase in international cooperation and financial support by the United States and other developed countries. The enormous challenge in developing countries, according to Chagas (1984; 1987), is for remote sensing and GIS technologists to develop new ways of integrating these technologies with existing economic and cultural aspects in a manner that respects and builds upon local talent and existing institutional infrastructures.

Basic Technology Needs. Remote sensing and GIS are relatively advanced technologies. They require advanced equipment and skilled individuals with special training in interdisciplinary analyses as well as support staff with advanced training in computer science and electronics. An organizational infrastructure must be present to provide basic technology needs for effective remote sensing and GIS integration. Basic needs may vary from such items as constant, 115-volt power sources and appropriate air conditioning to complex, high-speed computer networks and associated staff. While these basic technology needs are usually met in developed countries, there are multiple barriers to high technology implementation in developing countries.

Life Cycle Versus Procurement Cycle. Integration of remote sensing and GIS technologies requires combining sophisticated analytical photogrammetric and digital image processing workstations and GIS workstations. These workstations are adding capabilities faster than most procurement cycles can be carried out. Standards written for a state-of-the-art capability at one point in time may be eclipsed by advances in hardware and software during the procurement cycle. In many cases, advances are impossible to anticipate, and procurements may be outdated even before final orders are completed. Institutions need to carefully weight the costs and benefits of incorporating new software and hardware in a cycle that probably does not exceed three years. This scenario is especially difficult for Federal institutions because their procurement and implementation cycle is approximately three years, as well. Leasing rather than purchasing equipment may be a viable option in the future.

Interdisciplinary Work Mechanisms. Remote sensing and GIS are essentially interdisciplinary in nature. Most organizations are formed along a disciplinary core, such as hydrologists, foresters, urban and regional planners, or air quality specialists. Integration of these activities requires new organizational infrastructures with a focus on the interdisciplinary nature of the technologies. Yet, disagreements over jurisdiction, funding, and responsibility often form barriers in addition to the technical barriers inherent in understanding and applying the technologies themselves.

Interagency/Intergovernmental Work Mechanisms. As organizations become more institutionalized, they tend to view their own work as the main center of activity. The process often results in attitudes, procedures, guidelines, and rules that hinder the free interchange of information. Examples of this are long agency review cycles for scientific information, lack of common data dictionaries and classification procedures for data, and perceived needs for the maintenance of data confidentiality. All of these factors limit opportunities for cross-fertilization of ideas from institution to institution. Resources are viewed as scarce items to be protected and directed toward the goals and priorities of the "owning" organization. In the extreme, Landsat imagery purchased for a hazardous waste study may be prohibited from being used within the same organization for an ecological study just because it was purchased by another part of the organization and cannot be shared due to trade secret restrictions.

SUMMARY AND SUGGESTIONS FOR FUTURE RESEARCH

The objective of this paper is to gain a better understanding of the institutional issues that constrain the development, integration, and use of remote sensing and GIS technologies. Many of the constraints on the management and use of digital geographic, cartographic, and remotely sensed data are institutional rather than technical in nature and a better understanding of these issues could lead to advancements in remote sensing and GIS.

Six issues are explored, which in no way is meant to be a complete and thorough examination of the broad, complex subject of institutional issues. The first issue is data availability, including the problems of finding data, of nonexistent data, and of data sharing. The difficulties of marketing digital spatial data and establishing appropriate data costs also are reviewed in considerable detail. Second, the case of civilian satellite remotely sensed data costs is presented which raises a question of national significance—should these data be viewed as an economic resource or a public good? The third issue, equipment availability and costs, is examined in light of the problems of limited budgets, inadequate support staff, evolving technologies, and public domain software. The shortcomings in the area of professional standards and practices are reviewed as the fourth issue. Considerable emphasis was given to the fifth issue, education and training. Here the problems of who performs the education and training, training in field techniques, knowledge of fundamental principles, use of analog versus digital data, data set availability, and core curricula are explored. The sixth issue deals with the institutions themselves and the problems in organizational infrastructures, including long-term commitments, basic technology needs, life and procurement cycle, and interdisciplinary and interagency/intergovernmental work mechanisms.

The examination of institutional issues surrounding remote sensing and GIS technologies also suggests several opportunities for future research.

Data

- Evaluate how spatial data are used in the decisionmaking process.
- Evaluate how spatial data are managed in the public sector.
- Evaluate how institutions provide spatial data.
  - —open versus restricted access
  - —information as a public good
  - —freedom of information/public records
  - —value of multiple uses of information
- Define mechanisms for improved sharing of data.
- Define mechanisms for improved exchange of information about data.
  - —electronic bulletin board

Equipment

- Evaluate the integration of remote sensing and GIS technologies in different equipment environments, including supercomputers, mainframes, minicomputers, workstations, and PCs.
  - —advantages and limitations of each environment
  - —assess environments for optimal technology use

Standards

- Define common geoprocessing languages for interdisciplinary use.
  - —glossary
  - —user friendly interface (e.g., icons)
  - —potential for technology interface
- Explore methods for developing and documenting standard procedures.

Education/Training

- Explore options for enhancing core curricula.
  - —integration of remote sensing and GIS technologies
  - —technology implementation for public agencies
- Explore options for creating and distributing teaching modules.
  - —advanced telecommunications
  - —media (e.g., CD-ROM)

Organizational Structures

- Define models and identify incentives for forming creative consortia.
  - —among levels of government
  - —among academia/industry/government sectors
  - —among professional organizations
- Explore optimum intraorganizational structures (where does the work get done?).

Clearly, institutional issues are as important as technical issues in understanding remote sensing and GIS technologies. The suggested research agenda for institutional issues is only a partial listing of areas that need further study. Positive efforts already are underway such as the development of the National Geographic Data System and the work being done in education and training by the National Center for Geographic Information and Analysis and by several professional societies. If, however, additional progress could be made toward a better understanding of the issues and possible solutions, a commensurate overall improvement would occur in the integration and use of remotely sensed data and GIS techniques.

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