AUTO-CARTO 5

PROCEEDINGS

AUTO CARTO 5

Environmental Assessment and Resource Management

Sponsored by
American Society of Photogrammetry
and
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INDEX BY TITLE

INDEX PAGE

INDEX	PAGE

INDEX	PAGE

INDEX BY AUTHOR

THE ROLE OF THE USFWS GEOGRAPHIC INFORMATION SYSTEM IN COASTAL DECISIONMAKING

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ABSTRACT

Unprecedented demand on coastal resources in the 1980's has generated a need for valid information and analyses to support wise management of the coastal zone. The National Coastal Ecosystems Team of the U.S. Fish and Wildlife Service recently implemented a geographic information system to enhance its ability to analyze and display environmental information about the coastal zone. Outputs from this system have been presented to the State of Louisiana Senate and House Committees on Natural Resources and to the Congressional House of Representatives Committee on Merchant Marine and Fisheries. The purpose of this paper is to describe the use of the Map Overlay Statistical System for addressing selected coastal issues and to discuss its utility for coastal decisionmaking.

INTRODUCTION

In 1975 the U.S. Fish and Wildlife Service (USFWS) initiated a coal project primarily aimed at developing information and technology to manage western coal development in an environmentally sound fashion. Early in this project it became obvious that most of the information needed for Federal coal-leasing decisions existed in map form, primarily within the Bureau of Land Management's District Offices and the Service's Western Energy and Land Use Team in Fort Collins, Colorado. The sheer volume, variety, and geographic coverage of map information needed to make these decisions were staggering and required a system for efficient management and analysis.

The development of a geographic information system for the Service was managed by the Western Energy and Land Use Team. Their first task was to review existing systems nationwide and determine if a system or part of a system existed that would fulfill management and analysis needs. A number of systems, particularly those in the U.S. Forest Service, Bureau of Land Management, and U.S. Geological Survey, as well as a number of States, had components that were powerful and transportable. No system was found that would meet all needs, therefore, the Service decided to construct a geographic information system beginning with subsystems selected from existing software. A geographic information system focusing on analysis called the Map Overlay Statistical System (MOSS) was developed.

At the same time MOSS was under development, another system, aimed at providing operational support to the Service's National Wetland Inventory, was also under development. So that these two efforts would complement one another, the Service decided to focus the Wetland Inventory effort on data entry. A system consisting of both software and hardware was developed that could digitize information from a number of map scales and projections. The system was designed to be capable of meeting or exceeding national map accuracy standards, and to store information in latitude and longitude to accurately represent geographic positions on the earth's surface. The system that was developed and tested was called the Wetlands Analytical Mapping System (WAMS). More recently, this system has utilized an APPS IV stereoplotter to digitize directly from stereo-paired aerial photography.

The National Coastal Ecosystems Team (NCET) recognized the need for geoprocessing capabilities and initiated steps towards acquiring these capabilities in the fall of 1979. Several criteria were used to select a combination of systems that were already available within the USFWS. These systems were installed and brought to operational status in late April of 1981. They included (1) the Wetland Analytical Mapping System for data entry, (2) the Map Overlay Statistical System for data analysis, and (3) the Cartographic Output System (COS) for data display.

THE SYSTEMS

Data Entry System

Data entry at NCET is performed with the Wetland Analytical Mapping System (WAMS). WAMS is an interactive, menu-driven, digitizing, and map-editing system which allows various types of data to be captured in digital format from maps or aerial photography. Aerial photography may be used if the vertical and horizontal positions of features are required; however, horizontal positions usually provide sufficient accuracy for most geographic analyses (Niedzwiadek and Greve 1979). Data entry operators at NCET, therefore, digitize the horizontal locations from map sheets, and the WAMS software checks to insure that national map accuracy standards are met. Digitizing from map sheets with WAMS requires a minimum of six known geographic coordinates to accommodate georeferencing algorithms to allow for the accurate georeferencing (USFWS 1980). Digitizing, editing, and verifying digital map products are conducted in an arc/node format and are data-based only after verification and polygon formation procedures have been passed without error. WAMS is scale and projection independent, capturing map coordinates in a latitude-longitude format. The edges of adjacent maps are also checked and verified during the digitizing process so that adjacent maps can be properly aligned.

After the maps have passed verification procedures without error, they are transferred to MOSS. During this transfer, data formats are changed and maps can be transferred to any one of 22 map projections (usually Universal Transverse Mercator Projection, UTM).

Map Analysis System

The analysis of geographic data is conducted with the Map Overlay Statistical System (MOSS). MOSS is an interactive or batch mode geoanalysis system designed for the analysis of natural resource information. Functionally, MOSS is utilized by responding to prompts from the system with an English language command and a map identifier (Reed 1980). The system executes the initiated command resulting in the generation of map or database summaries, tabular measurement information, statistical summaries, text files, interactive measurements of area, distance or location, graphs, plots, interpolated surfaces, and entirely new mapped information derived from user-specified criteria. Over 70 commands are available to perform these functions and can be utilized with a variety of georeferenced data types including text, point, line, polygon, raster, elevation point, and elevation grid (Reed 1980). Multiple attributes can be assigned to point, line, polygon, and raster data types. The functions of MOSS commands can be generally classified into five categories: (1) general purpose, (2) database management, (3) spatial retrieval, (4) data analysis and measurement, and (5) data display (USFWS 1982).

Data Display System

Although MOSS has display functions capable of plotting to a CRT, line printer, and a variety of plotters, the Cartographic Output System (COS) is most often used to generate final map products. COS is operated from a combination of interactive commands and menus and is based on the concept of generating and positioning data components inside of a graphic profile. Data components consist of entries or groups of entries recognized by the operator as being separate entities in a cartographically sound graphic product such as a legend, scale, or map overlay. The positions of these components are determined in the graphic profile according to operator-specified coordinates.

WAMS, MOSS, and COS are all operational on a Data General Eclipse Minicomputer S/250 at the National Coastal Ecosystems Team in Slidell, Louisiana. These systems have been used to address a number of coastal issues in the Gulf of Mexico and on the Atlantic seaboard. Products from these systems have been successfully used to influence funding to address national resource issues as well as to assist in site-specific locational decisions.

APPLICATIONS AND USE OF PRODUCTS

These geographic information systems are currently being used by a number of Federal and State agencies throughout the United States to highlight and analyze resource-related issues. Applications at the Coastal Team have addressed numerous environmental issues. Some of the major types of analyses include (1) habitat trend and change analysis, (2) dredged disposal and port development, (3) permitting and accumulative impacts, (4) modeling habitat impacts from energy development, (5) environmental impact statements for

OCS oil and gas leasing program, (6) modeling oil spill vulnerability of coastal areas, and (7) wildlife distribution and vegetation analysis. The following section discusses selected projects that have been completed or are ongoing at NCET.

Habitat Trend Analysis

Habitat trend analyses are being conducted in selected areas of every State bordering the Gulf of Mexico. The single most effective project analyzing habitat trends was conducted for the active delta region of the Mississippi River.

This project, entitled "The Mississippi River Active Delta Project," was the first project initiated and completed at NCET. In April of 1971, the New Orleans Disctrict U.S. Army Corps of Engineers (USACE) and USFWS's Field Office in Lafayette, Louisiana, requested assistance from NCET to measure wetland changes in natural subdeltas of the Mississippi River active delta to allow USACE and USFWS to more effectively manage activities according to natural hydrologic units. This request was made in reply to the mandate to dredge and maintain the Mississippi River channel at 55 feet as opposed to 35 feet. The additional dredge material produced from the maintenance of a 55-foot channel involves millions of cubic feet of sediment each year that had to be disposed of in the delta region. The USFWS proposed that the USACE use a portion of the dredge material to mitigate wetlands lost from leveeing the river.

The question of where to dispose of the dredged material remained an issue for USACE and USFWS. Acreage measurements and graphics depicting habitat trends were requested to locate appropriate sites for dredge disposal, marsh mitigation, and freshwater and sediment diversion. The USFWS also realized that, despite the release of planimetered change measurements by NCET indicating alarming rates of wetland changes in recent decades, a depiction of the change was required to show more effectively the dramatic alteration of wetlands. Two sets of products, therefore, were generated: (1) area measurements and graphics indicating change in each subdelta, and (2) area measurements and graphics indicating change in the entire delta (Figure 1 and Table 1).

Table 1. Comparison of area summaries for the Mississippi River Active Delta in 1956 and 1978.

HABITAT TYPE	1956 ACREAGE	1978 ACREAGE	ACREAGE CHANGE	% CHANGE
MARSH	182,838	89,381	-93,457	- 51%
FORESTED WETLAND	7,894	3,233	- 4,661	- 59%
UPLAND	3,362	6,915	+ 3,553	+ 106%
SPOIL	3,057	11,369	+ 8,313	+ 272%

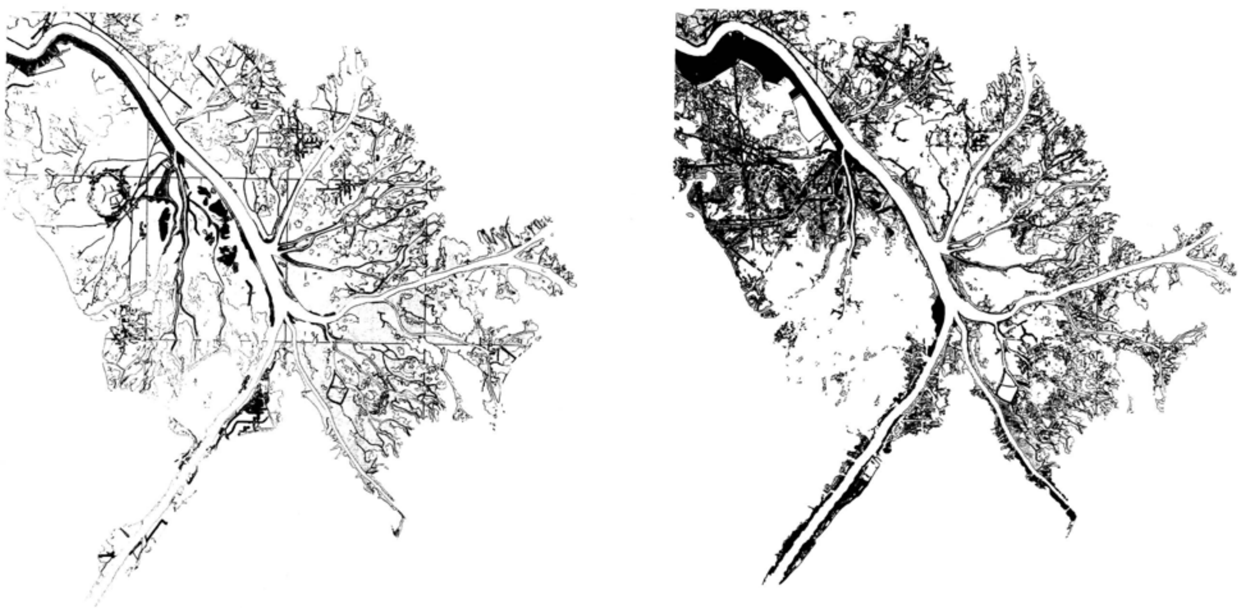

Figure 1. Mississippi River Active Delta as it appeared in 1956 and 1978.

Graphic products and reports from this project have not only been used by USACE and USFWS for regional and site-specific locational decisions, they have also been presented before Parish, State, and Congressional legislative bodies. Products from this project have been presented to the Louisiana Senate and House Committee on Natural Resources by Senator Samuel B. Nunez, Jr., to highlight and portray the dramatic problem of coastal wetland alterations incurred by man's activities (Nunez and Sour 1981). Senator Nunez's presentation contained the major graphical display of wetland change to the committee. The State of Louisiana later allocated $35 million to various State agencies and organizations in an attempt to address the serious problem of wetland loss. Other uses of these products have influenced similar results, although not as dramatic, at hearings before a subcommittee of the House of Representatives in Washington, D.C. (Johnston 1981). High quality graphics and professional delivery of those products and information, therefore, have significantly affected State and Federal decisions concerning coastal resources. Products are also being used by a number of educational institutions such as the Louisiana Nature Center and Louisiana State University.

Dredge Disposal and Port Development

The Mobile District U.S. Army Corps of Engineers (USACE) required the use of geoprocessing capabilities to effectively analyze the potential impacts of depositing dredge material in coastal areas. The dredge material disposal problem arose from the Corps' mandate to deepen Pascagoula and Mobile Bay ship channels from 35 to 55 feet deep. NCET has constructed a large geographic database consisting of wetland and deep water habitats, benthic assemblages, bottom sediments, salinity, archeological sites, artificial reefs, oyster leases, distribution of 23 species of finfish and shellfish, oyster reefs, bathymetry, and current dredge disposal sites. The geographic analysis of multiple resource overlays are being conducted to select sites for dredge disposal and to measure the impacts of fish and wildlife resources with disposal actions. This continuing program should assist USFWS and USACE in minimizing the impacts of dredge disposal on important marine and estuarine resources. Cartographic modeling of the entire Mississippi Sound and Mobile Bay is currently being negotiated as an additional analysis for delineation of the most sensitive offshore biological communities.

BLM Environmental Impact Statement for Offshore Oil and Gas Leasing

The current administration has opened up vast areas in the Gulf of Mexico to oil and gas exploration. The Bureau of Land Management's Offshore Continental Shelf Office (now Minerals Management Service, MMS) was required to write an environmental impact statement on oil and gas exploration for the entire Gulf of Mexico. NCET was requested by the Assistant Director of the Department of Interior to assist MMS in gathering data and calculating areal and linear measurements of coastal resources in the gulf. Areal and linear measurements had to be conducted for a number of political and planning unit areas, ranging from the county level to extensive offshore planning units. Standard U.S. Geological Survey 1:250,000 scale geounits were used as base maps for a study area which consisted of the entire Gulf of Mexico. Tabular summaries of resource information were generated for each county bordering the coast. These summaries included the distance or length of shoreline features along the coast, including recreational beaches, mangroves, marshes, etc. Area summaries were also calculated for important offshore resources such as seagrass beds, nursery grounds, and shellfish concentration areas. Each geographic unit, i.e., county, was then ranked in terms of resource priority based on these measurements (MMS 1982). Oil and gas leases will be given an environmental ranking according to their proximity to the areas and the probability of an oil spill reaching the most important coastal areas.

A second analysis for the impact statement was conducted for scattered areas in the gulf consisting of live bottoms and restricted areas where oil and gas activities are limited. These restricted areas were delineated according to their distance from live bottoms or no activity zones where no oil and gas activities are permitted. Zones range from 1 to 4 miles, with more restrictions enforced in the zones closer to live bottom areas. MMS requested the acreages and percentage of each oil lease block occupied by the live bottom areas and various restricted activity zones. The lease blocks and the restricted activity zones were digitized for 12 areas at a scale of 1:120,000. MOSS was used to generate color graphics and area summaries of the intersections between the lease blocks and zones (Figure 2 and Table 2). MMS used these figures to assign an environmental ranking to each block based on the area and percent of each block within the restriction zones (MMS 1982). Quantifying the effects of Outer Continental Shelf oil and gas development on coastal ecosystems will continue for the next 3 years.

Table 2. Acreage summaries for lease blocks A367 and A368.

SUBJECT		AREA	FREQUENCY	PERCENT
A367	4 MILE/ZONE	3491.85	1	60.78
A367	1 MILE/ZONE	1973.96	1	34.36
A367	NO ACTIVITY	279.48	3	4.86
TOTAL (IN ACRES)		5745.3	5	100.00
A368	3 MILE/ZONE	1205.58	1	21.03
A368	1 MILE/ZONE	1211.77	1	21.13
A368	4 MILE/ZONE	3289.45	1	57.37
A368	NO ACTIVITY	26.93	1	.47
TOTAL (IN ACRES)		5733.7	4	100.00

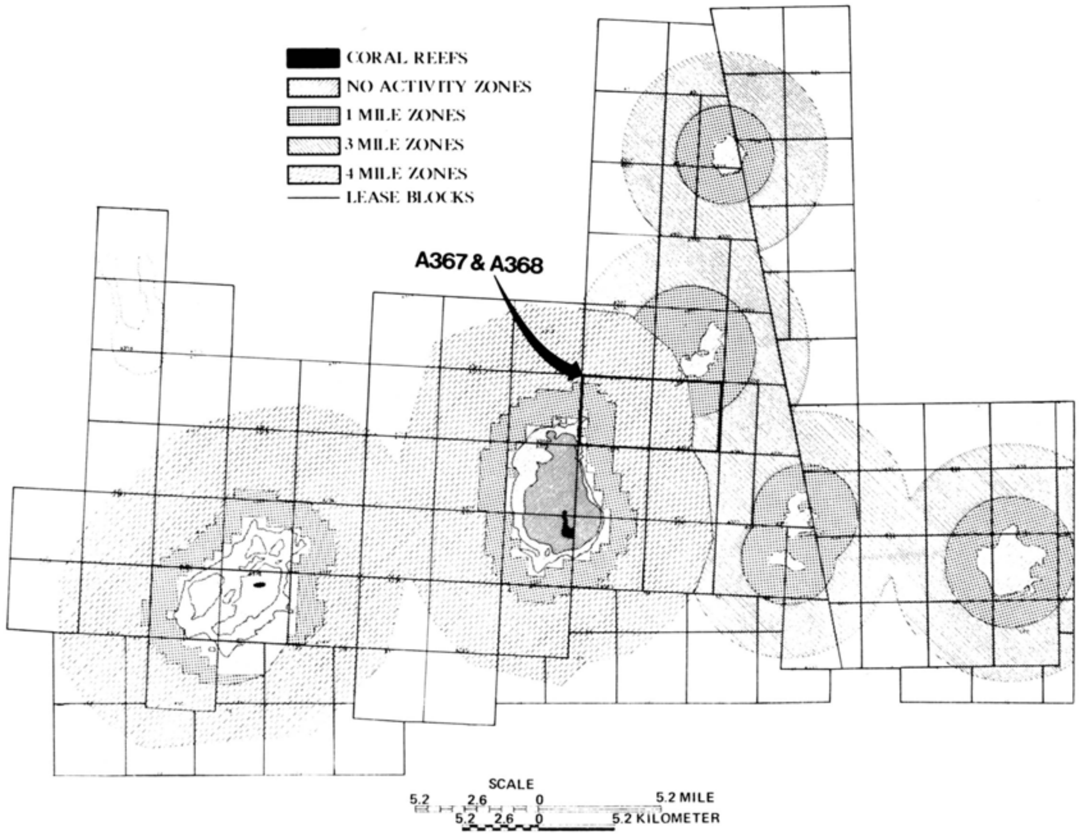

Figure 2. Plot of offshore lease blocks in West and East Flower Gardens.

Oil Spill Vulnerability Modeling

A recent pilot project undertaken by NCET for the Louisiana Offshore Oil Port (LOOP) produced a composite map depicting protection priorities for onshore and nearshore areas in the event of an oil or toxic chemical spill. The project demonstrated the use of MOSS cartographic modeling capabilities to indicate the vulnerability of different geographic areas to oil and toxic chemical spills.

The Barataria Pass quadrangle in coastal Louisiana was selected for the study area. Inputs for the analysis consisted of eight resource variables: wetland habitats, oyster leases, recreational beaches, historical sites, endangered species, bird rookeries, marinas, and water intakes. These resource variables were ranked from low vulnerability (1) to high vulnerability (3). Ranking criteria consisted of a previously developed methodology for ranking biological habitats (Adams et al. 1982), and methods utilized by the New Orleans MMS office. Resource maps were digitized and the all point data were buffered with distance factors to indicate zones of proximity to the resource. Resource overlays were converted to a cell format and recoded to the appropriate value determined by the ranking criteria cited above. The cell maps were arithmetically composited using cartographic modeling methods to produce single map indicating oil spill vulnerability. Vulnerability index values were grouped into logical classes to produce a final map product that depicted three levels of vulnerability: (1) low vulnerability, (2) medium vulnerability, and (3) high vulnerability. Figure 3 depicts the distribution of these values in the Barataria Pass 7½' USGS quadrangle.

Additional work and products will facilitate oil spill cleanup activities and deployment of spill response personnel in order to protect those areas of highest vulnerability. Data will be available on NCET's computer system with an offsite graphics terminal and in atlas form plotted on opaque stable base material. The opaque overlays will be overlayed on USGS quadrangle for visual geographic referencing. This particular application has utility in hazardous waste and oil spill management, environmental impact assessments, effluent discharge assessment, and development contingency plans for the cleanup and deployment of spill response personnel.

SUMMARY

The National Coastal Ecosystems Team is using geoprocessing methodologies to assist agencies who have legislative mandates or responsibilities to manage coastal resources. The above case studies illustrate how NCET's geographic information system was and is being used to address a variety of coastal issues. These studies are not a complete review of applications at NCET; however, they provide a record of the types of analyses that are being applied to resource issues in coastal and offshore areas using GIS technology. Color graphics and tabular summaries produced at NCET have helped

Figure 3. Oil spill protection priority index map.

influence important environmental decisions on a variety of levels.

To have significant impacts, these materials had to be presented by professional witnesses who were well versed in the complexity and problems associated with biological systems and who can effectively present facts and conclusions at local, State, and Federal legislative levels.

In conclusion, if management of coastal ecosystems is to be based on the best available information, it is imperative that this knowledge be transferred to decisionmakers in a form that is readily accessible and understandable. Geoprocessing techniques at NCET have provided the means for accurately analyzing and portraying information for use by scientists, administrators, and lawmakers at many levels. The result has been a successful rapport between various Government officials and a significant impact on coastal decisionmaking.

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DIGITAL MAPPING IN A DISTRIBUTED SYSTEM ENVIRONMENT

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ABSTRACT

Over the last two decades there has been a gradual advancement of digital technology within most mapping organizations, especially in the fields of photogrammetric computer mapping and computer-assisted cartography, the efficiency of which is greatly influenced by the processes of data acquisition, the encoding of various information for storage, and the manipulation of data within the system.

The current trend in system development (hardware, software and operation) is directed towards the configuration of sub-systems in a distributed computer network. The development of distributed systems is a natural outgrowth of the requirements to increase our computational abilities and to optimize the sub-systems resources. Even though the individual components operate autonomously, the common master data base is the unifying element. The configuration of the total system depends mainly on the user requirements, the availability of the system to various users, the source of digitization (aerial photography, existing maps, etc.), the structure of the common topographic/cartographic data base, the interaction between the various sub-system components and the form of output.

The functional requirements of distributed digital mapping systems are described. The various methods that can be used to achieve the inter-connection between the various sub-systems, the communication mechanism and the characteristics of distributed data bases are also given.

INTRODUCTION

The most compelling benefit of digital mapping in a distributed system environment is the ability to share information. Distribution means not only one program can visit many different processors, but, conversely, that one processor and its associated data bases can be accessed by many different sub-systems. Time-sharing is not a new idea. Time-sharing was developed out of the need to obtain raw computing power at reasonable cost, and data sharing was initially viewed as a secondary benefit.

Today, the economics have changed considerably to the extent that raw computing power is available at low cost through microprocessors and minicomputers thereby reducing the need to share a processor for computational power alone. While this suggests that there may be a shift in emphasis from time-shared computers to stand-alone dedicated systems, the recent trends are directed towards the multicomputer configurations, mainly because of the need to share the data bases.

The increase in adapting digital technology in mapping organizations and the success achieved in automating the various topographic/ cartographic processes, coupled with the desire to optimize sub-systems resources are focussing the attention of system designers, managers and users to the need for building digital topographic data bases. In large mapping organizations, this can be achieved by automating the compilation of data base elements in the topographic map production processes. This includes the automation of the following functions: data acquisition, reduction, indexing, storage/retrieval, computation, analysis, editing, data base maintenance/management, and generation of output in digital or analog forms.

To achieve these objectives, it is necessary to design and develop a plan from a systems approach which integrates the following various functional activities into a unified production system:

- computer-aided photogrammetric map compilation,
- digital compilation using automated photogrammetric instruments,
- graphic digitization (manual, semi-automatic and/or fully automatic digitizing devices),
- automated cartography,
- editing and/or digital map revision,
- generation and manipulation of local data bases by various sub-systems, according to their functional activity,
- translation (restructuring) of local data base elements into a master data base,
- graphic output and digital output sub-systems, and
- etc.

The analysis of various production sub-systems (activities) clearly indicates that a distributed system environment is the most practical and efficient methodology to utilize in the system design.

FUNCTIONAL REQUIREMENTS OF DISTRIBUTED DIGITAL MAPPING SYSTEM

The functional requirements for a digital mapping system in a distributed environment can be summarized as follows:

1. Data Acquisition

The source material used for the digital compilation of topographic/ cartographic products are received in both analog or digital form. In the analog form, we find aerial photography and graphic maps, while digital sources include scanned aerial photographs or digital imagery acquired by airborne solid-state linear array cameras. The essence then is to capture the data digitally in order to provide the necessary input information for data base manipulation procedures.

1.1 Digitization from Analog Aerial Photographs

Computer-aided photogrammetric map compilation using analog aerial photography as source is achieved by the interfacing of photogrammetric plotters to digital computers. Varius system configurations have been successfully developed in numerous mapping organizations. As a prime example, we find the multiple-station digital photogrammetric compilation systems developed in the Topographical Survey Division, Surveys and Mapping Branch, Ottawa, Canada (Allam, 1979).

1.2 Digitization of Existing Graphics

Graphic sources are existing maps, photogrammetric manuscripts, orthophoto maps, etc., and the process of digitization is regarded as a conversion of data records from analog to digital form. This is achieved by:

a) manually retracing the graphic features on a digitizer table with a cursor or stylus,
b) employing a semi-automatic line-following device, or
c) processing the entire graphic automatically with a raster scanning digitizer.

In the first two methods, the output is a series of X and Y coordinates in the digitizer coordinate system. The third method produces a digital output in a raster format, which for data purposes requires conversion from a raster to a vector format.

Systems for digitizing existing graphics consist of multiple work stations (terminals) for data entry, display, editing, etc., interfaced to a digital computer.

1.3 Compilation from Digital Imagery

Digital stereo imagery may be acquired by scanning aerial photographs on automated photogrammetric instruments or in real-time by means of airborne linear array cameras. The compilation of topographic detail requires an automatic correlation (matching) of the conjugate digital stereo-imagery, while the compilation of planimetric detail requires a solution of the complex problems of digital image analysis and pattern recognition. This mode of compilation is heavily dependent on processing using digital computers.

2. Data Storage and Retrieval

Depending on the mode of data acquisition, the data is stored in a retrieval format in the sub-systems local data base. To build a master digital data base, the data is restructured according to a standardized digital data base, also in a retrievable format. The stored data must include positional coordinates and sufficient description information to make it useful across a spectrum of digital mapping products. In addition, they are stored at a resolution capable of supporting the majority of the products.

3. Data Manipulation

When a specific product is requested, the data contained in the master data base (or local data base) within the geographic area of interest is extracted and is used as input to the digitial manipulation process. This function requires several user dependent operations, and includes:

- selection of specific feature types,
- display of digital data,
- cartographic editing and enhancement,
- data compression,
- projection adjustment and transformations,

- mathematical processing/restructuring (e.g. generation of digital elevation models - DEM's),
- symbolization,
- statistical analysis,
- report generation, etc.

The output of the process may be a digital file structured according to a standardized digital exchange format or a digital file that can be used to drive a finishing device.

4. Graphic Output

This function entails the use of the digital data desired to produce the necessary map/chart overlays using automatic plotting/scribing devices. This function also includes a quality control task and other manual processes as required.

In addition to these four basic tasks a digital mapping system in a distributed computer network will support other functions such as:

- resource sharing
- system management and control
- batch processing and program development
- multiple user defined data base inquiry operations

DEVELOPMENT OF DISTRIBUTED DIGITAL MAPPING SYSTEM

A distributed system is achieved by interconnecting the computers of the digital mapping sub-systems in a manner that provides optimum interchange of digital data between the various sub-systems, in addition to the inter- change of data between the various terminals, graphic work stations and peripherals within each sub-system. In essence, the development of a distributed digital mapping system may be regarded as a computer network including hosts (central) computers, nodes (minicomputers), terminals (work stations, digitizers, video terminal, graphic editing stations, etc.), and transmission links.

A host in this context is a central computer whose function is separate from that of switching data. A node is a computer that primarily is only a switch. Some designs permit a computer to be both node and host. Terminals are interface between the user and computer network. Transmission links join the hosts, nodes and terminals together to form a network. A path is a series of end-to-end links that establishes a route across part of the network. The links and nodes along with the essential control, make up the communication sub-net, or the digital mapping data network.

Classification Schemes of Distributed Systems

Network topology, as a mean for categorizing digital data communication networks evolved from graph theory (Deo, 1974). Terms borrowed from graph theory include the previously defined host, node, link and path. This terminology forms the basis for topological classification of data networks as follows:

1. Centralized Network

It is essentially a star configuration (links radiating from a single node), is the simplest arrangement, as shown in Figure 1. This topological scheme requires a link to be dedicated between the central computer (node) and each terminal. This type of configuration is normally found in digital mapping sub-systems dedicated for one activity, e.g. computer-aided photogrammetric compilation. The reliability of the centralized network depends on the central computer (node). Its failure suspends all activity in the network, whereas individual link failures affect only a single device per link.

2. Centralized Network with Concentrators/Multiplexers

Where several terminals in a geographically dispersed system are close to one another, they are often connected to concentrators or multiplexers, which in turn are connected to the central computer as shown in Figure 2. The devices (normally microprocessors) obtain more efficient link utilization at the expense of an occasional delay in response time. A multiplexer is used where the information transfer rate of all simultaneously active terminals never exceeds the information transfer capacity of the link to the central node; but where the potential input capacity exceeds link capacity a concentrator is necessary because of its storage capacity. Concentrators can also merge several low-speed links into one high-speed link. However, concentrators and multiplexers cannot save a network when the central node fails.

3. Decentralized Networks

As shown in Figure 3, a decentralized network is an expanded centralized configuration with the concentrators/multiplexers replaced with minicomputers or microcomputers (nodes), having more memory and storage capacity. The added reliability of decentralized processing power comes at the expense of additional computers (nodes) and corresponding connecting links which permit some paths to be duplicated. Within reason, the reliability of the network can be increased almost indifinitely by duplicating paths and adding links and nodes.

4. Distributed Networks

As shown in Figure 4, a distributed network is similar to the decentralized configuration, but with each node connected to at least two other nodes in mesh form. A single ring is the simplest form, with each node connected exactly to the two other nodes. Each node can switch systematically between links according to a routing algorithm, to maximize the capacity of the network.

Distributed networks could be designed with a homogeneous structure, that is identical hardware at each node or hierarchical. In hierarchical configuration, there exists several sub-nets connected to one or more nodes. This hierarchy will allow for the use of various types of computers with varying power and function at each level and the backbone processor of such a system configuration is designated for the master data base. This type of hierarchical form makes it difficult to differentiate between the decentralized network structure and the distributed network and presently most designers can no longer distinguish between the two classes.

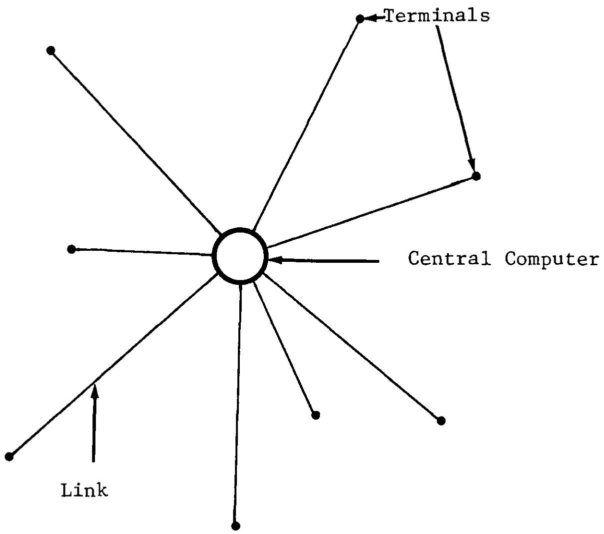

Figure 1 Centralized Network

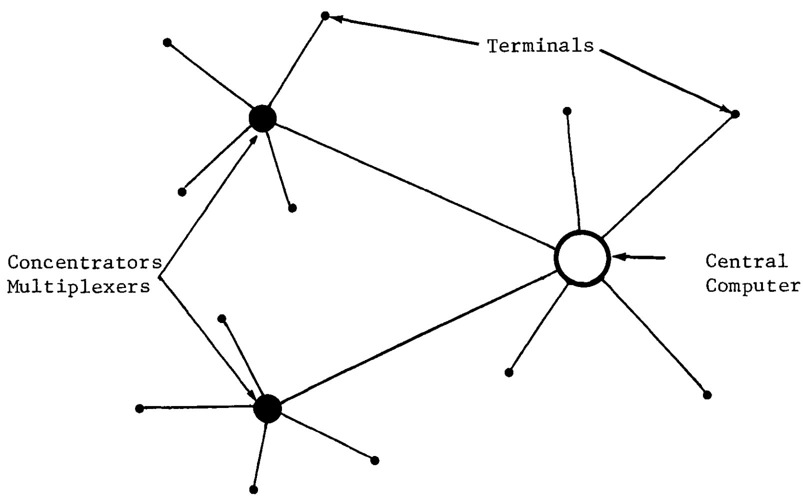

Figure 2 Centralized Network with

Concentrators / Multiplexers

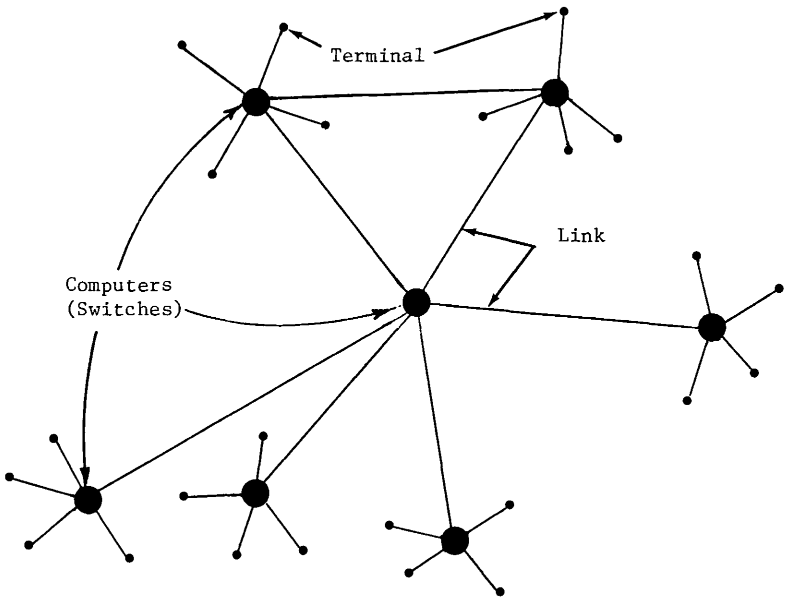

Figure 3 Decentralized Network

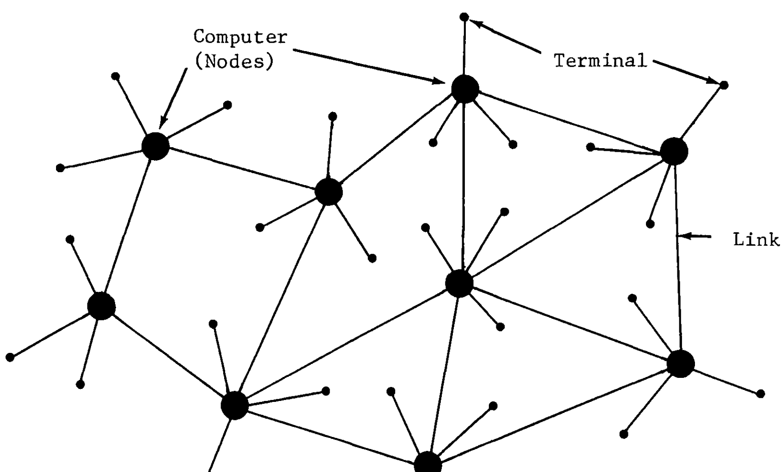

Figure 4 Distributed Network

COMMUNICATION AND NETWORKING

As shown in Figure 5, it would be a relatively straightforward task to design and build a communication mechanism whereby two programs, residing in the same computer, can send information or messages to each other. This is what is commonly known as interprocess communication facilities in operating systems.

In a distributed system the communication between programs reside in separate processors and hence a distributed communication mechanism must be created. Two halves of a single mechanism or service must communicate and synchronize to perform a unified function. This communication is used not only to pass information between the systems but also to pass control information between the communication mechanism programs them- selves. For that, a communication protocol is needed and is the only connection between the two distributed parts as shown in Figure 6.

Software is needed to enable multiple digital computers to be interconnected. This software is normally implemented as a set of layered network protocols, each of which is designed to fulfill specific functions whithin the network.

Software for each digital mapping sub-system activity, whether a data acquisition sub-system(s), data manipulation sub-system, data base sub-system or output sub-system, will be implemented as application software. This software must be designed and developed to achieve a synchronization of the system activity across multiple processors with the objective of sharing local data bases within each sub-system and the master data base containing the central data files.

DISTRIBUTED DATA BASES

The successful implementation of many distributed systems requires solutions to problems of data management in a distributed environment. These problems include data collection, concurrency control and update processing, failure recovery, and query processing.

In a distributed digital mapping system, data collection is fulfilled by the data acquisition sub-systems, and creation of local data bases. To collect the data in a central (master) data base, translation programs are necessary to reformat the files according to a standardized data base structure.

The coordination of concurrent updates initiated by multiple users must be done in a way that preserves the consistency of the data base. Updating should be made according to a data base manager program which acts on updates based on their sequence and/or time of requests.

Distributed system should have a failure recovery mechanism allowing the system to operate in a resilient manner and preserving the integrity of the data base. Ideally the system should continue functioning, although perhaps in a degraded mode.

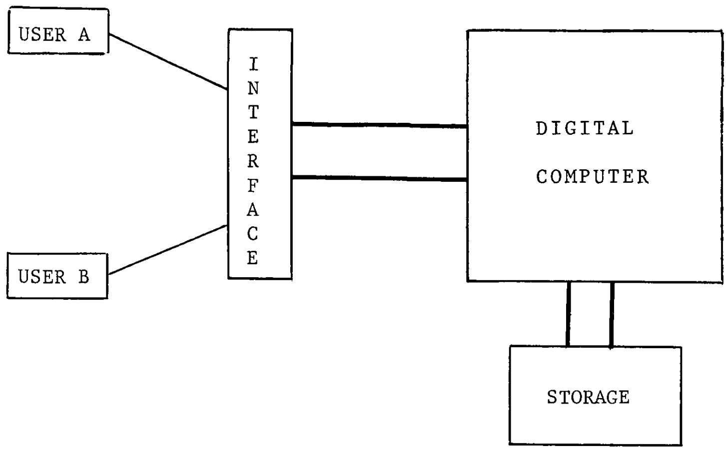

Figure 5 Local or Centralized Communication Mechanism

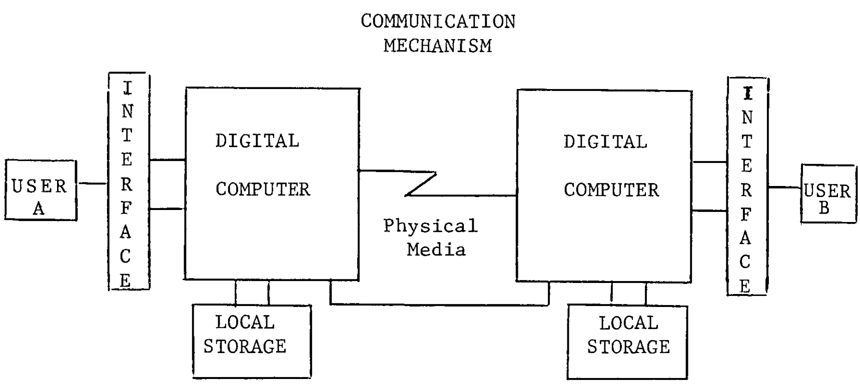

Figure 6 Distributed Communication Mechanism

Locating stored data in a distributed system will be simplified if the data is translated and transferred from the local data bases, in each digital mapping sub-system, to the master data base. If this is not the case, the distributed system program must determine where the data required by a query is stored. This problem can be solved by using a distributed data base management system, which allows the data to be sorted at multiple locations in the network and yet accessed as a single unified data base.

In a digital mapping environment, the approach of constructing a central data base from local data bases generated by various sub-systems will be preferred, due to the need for the exchange of digital map data among various organization/users, not directly linked to the distributed digital mapping system.

CONCLUSION

Distributed data processing systems are a new class of organizations and operations that exhibit a high degree of distribution in all dimensions, as well as a high degree of cooperative autonomy in their overall operation and interaction. By interconnecting the digital computers controlling various digital mapping sub-systems in a distributed environment, large mapping organizations will benefit from the improved performance, improved system availability, easier adjustment to a growing workload, extended control over computer resources, and the advantage of master digital data base. The dramatic drop in the cost of computers versus the increased cost of software and computer personnel makes distributed systems inevitable.

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AN OVERVIEW OF DIGITAL ELEVATION MODEL PRODUCTION AT THE UNITED STATES GEOLOGICAL SURVEY

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ABSTRACT

The U.S. Geological Survey (USGS), through the National Mapping Program (NMP), has the objective of preparing and making available multipurpose maps and fundamental cartographic and geographic information to meet the diverse requirements of users throughout the nation. The NMP concentrates on gathering those base categories of data depicted on topographic maps. There is an inherent relationship between two of these categories: orthophotographic imagery and hypsography. The National Mapping Division (NMD) of the USGS has been producing standard orthophoto products from high-altitude aerial photographs using automated orthophoto equipment since the mid-1970's. Byproducts of this operation are arrays of digital elevations that can be post-processed into digital elevation models (DEM's). Data collection techniques and constraints, while not affecting the quality of the orthophoto imagery, may impact the geomorphic fidelity of the digital terrain byproduct. This paper describes the collection of DEM data by the NMD, the means by which data errors are introduced and identified, and the editing techniques that may be employed to improve the quality of DEM's to meet user requirements.

INTRODUCTION

History

In the 1970's, two efforts within the NMD (then Topographic Division) of the USGS converged to create the digital elevation model (DEM) production system as it exists today.

- Since the mid-1960's, increasing user acceptance of and demand for orthophoto products had spurred efforts to develop a means of using digital input data to control automated operation of the T-61 and T-64 Orthophotoscopes. The use of digital profile data to control the z-motion of the exposing projector of the orthophotoscope was seen as a means to both increase production and improve image quality. This effort

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culminated in the development of the Digital Profile Recording and Output System (DPROS), which records digital profiles on magnetic tape in a format that can be used to produce DEMs as well as orthophotographs (Lemeshewsky and Shope, 1977).

- In 1974, a growing recognition of the potential use of cartographic data in digital form led to the initiation of a formal requirements study to define a digital cartographic data base to supplement the topographic mapping program (Office of Research and Technical Standards, 1975). Serving as input to this study was a cooperative research project in which NMD agreed to furnish terrain elevations and planimetric data in digital form to the Geologic Division, USGS for use in a computerized Coal Resources Information System (Elassal, 1975). One conclusion of this project was that the most cost-effective means then available for obtaining digital elevation data was the recording of profiles from stereomodels (Branch of Cartography, 1976).

In 1977, the study efforts came together when the National Mapping Division established a Digital Applications Team (DAT) to develop a capability to produce digital cartographic data as a standard product of the National Mapping Program. Some digital profile data sets, generated as a byproduct of orthophoto production, were already available. These data sets were stored in the regional office in which they were collected. In addition, the Division in 1976 procured an automated image correlation system, the Gestalt PhotoMapper II (GPM2), to produce slope-corrected orthophotos. Like the manual profilers, the GPM2 is capable of generating digital elevation data. Raw elevation data sets, generated by the GPM2 during the production of orthophotos, were also stored. The DAT developed formats and standards for the classification of DEM data which were adopted for internal use by the Division. As a result, starting in 1979, the raw elevation data sets have been processed into the NMD's standard digital elevation model format (U. S. Geological Survey, 1980).

DEM Organization

"Digital elevation model" (DEM) is the terminology adopted by the USGS to describe terrain elevation data sets in digital form. A standard DEM has the following characteristics (U. S. Geological Survey, 1980):

- It consists of a regular array of elevations cast on the Universal Transverse Mercator (UTM) coordinate system.

- The data are stored as profiles in which the spacing of the elevations along and between each profile is 30 meters.

- The unit of coverage is the 7.5-minute quadrangle; no overedge coverage is provided.

- Not all profiles have the same number of elevations.

- It contains approximately 138,000 (at 50 N. latitude) to 195,000 (at 25 N. latitude) elevation points.

The DEM's are classified into three levels according to the quality of the model:

- Level 1-- Raw elevation data sets in a standardized format. Only gross errors in data capture have been eliminated.

- Level 2-- Elevation data sets that have been smoothed for consistency and edited to remove random errors.

- Level 3-- Elevation data sets that have been edited and modified to insure positional consistency with planimetric data categories such as hydrography and transportation.

Virtually all of the DEM's produced to date are considered to be level 1 (McEwen and Jacknow, 1979; McEwen and Calkins,1981).

Digital Cartographic Data Base

To satisfy requirements of the National Mapping Program, the NMD is building a Digital Cartographic Data Base (DCDB) containing certain base categories of cartographic and geographic data. The DCDB consists of eight sublevel data bases which allow the digital cartographic data archived on magnetic tape to be indexed in several ways. One of the types of cartographic data indexed in this manner is the DEM. The DCDB currently manages in excess of 7,500 DEM's. Of this number, 70 percent were produced from raw data generated using GPM2 equipment. The GPM2 instruments have been used primarily to produce orthophotos in mountainous areas in support of Federal land and resource management agencies (McEwen and Jacknow, 1979). This is reflected in the present contents of the data base (See fig. 1).

DEM's in the DCDB are stored in one of two sublevel data bases as determined by the tested vertical accuracy: less than 7 meters vertical root mean square error (RMSE); and 7 to 15 meters vertical RMSE. The 7 meter RMSE was determined to be a reasonable standard for DEM's derived from 40,000 foot high-altitude aerial photographs, attainable under a variety of terrain conditions and instrument constraints (Brunson and Olsen, 1978). Less accurate data sets are retained if they are the best available.

COLLECTION

To meet present user requirements for DEM production, the National Mapping Division uses three systems to collect the digital elevation data. They are (1) the Gestalt PhotoMapper II (GPM2), (2) manual profiling from stereomodels, and (3) the Digital Cartographic Software System (DCASS).

The GPM2 is a highly automated photogrammetric system designed to produce orthophotos, digital terrain data, and photographic contours. An electronic image correlation component of the GPM2 measures parallaxes of 2,444 points

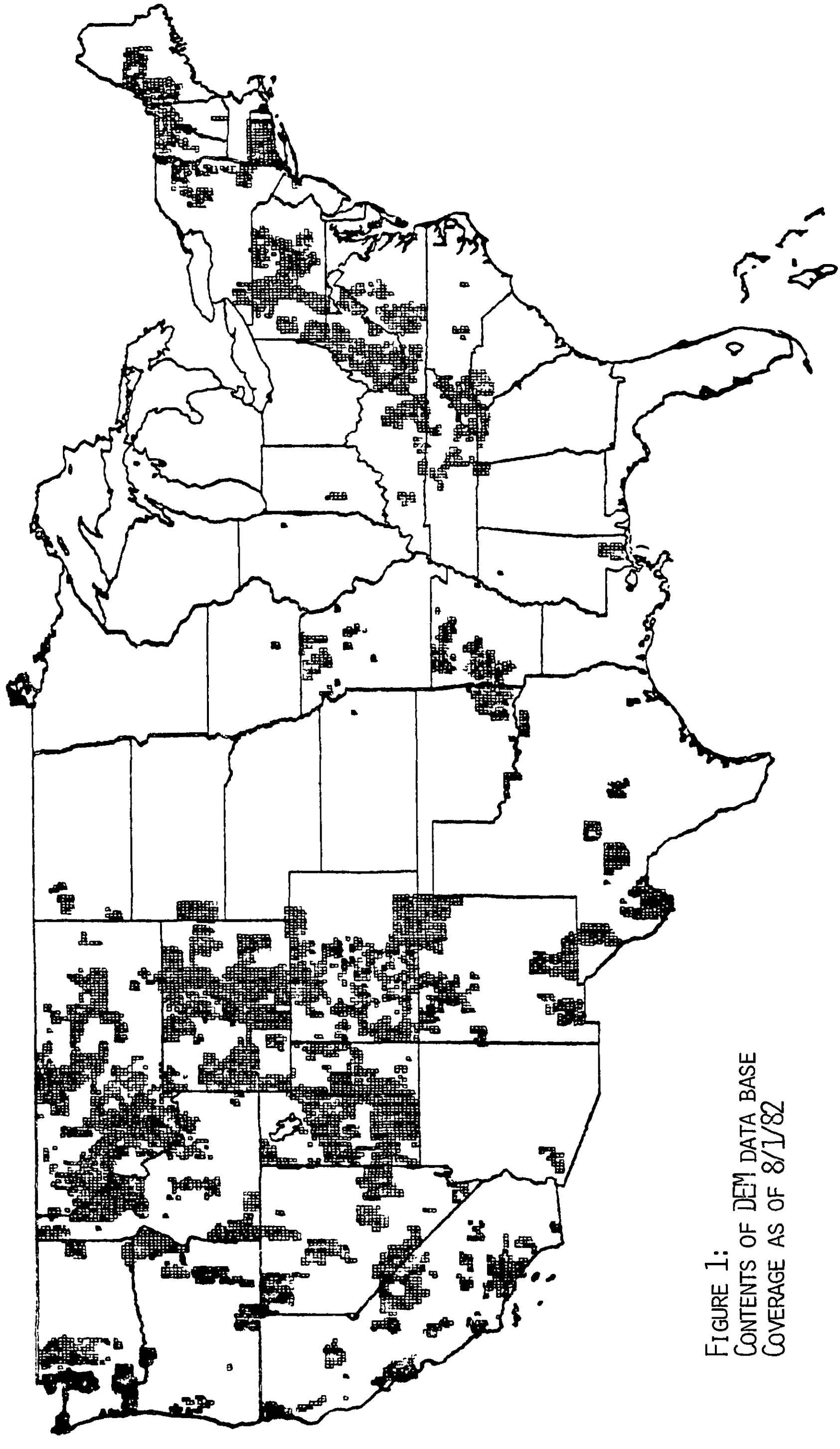

FIGURE 1:
CONTENTS OF DEM DATA BASE
COVERAGE AS OF 8/1/82

within each 9- x 8- millimeter area of a photogrammetric stereomodel.Of these 2,444 correlated points, subunits of 576, 1,024, or 1,600 points are collected for inclusion in the elevation model. These subunits are called "patches" and the patch size is selected to accommodate various terrain conditions. The horizontal (x and y) resolution of the elevation points within each patch is approximately 182 micrometers at photo scale (a ground distance of 47 feet when using high-altitude photography at 1:80,000-scale). Each of the two stereomodels covering a standard 7.5-minute quadrangle contains over 500,000 correlated points, which are regridded to form a DEM in the standard DCDB format.

The manual profiling systems use stereoplotters, interfaced with electronic digital profile recording modules, for scanning of stereomodels in the photo y direction. Image-density-controlled high-altitude aerial photographs are used as source material. The scan speed and slot size (stepover interval) can be varied by the operator to accommodate differential changes in topographic slope. A 4- millemeter slot size is most commonly used; thus profiles are spaced approximately 300 feet apart. Elevations are normally recorded every 100 feet along each profile. The raw elevation data are reformatted and regridded to the standard DCDB format and tested for vertical accuracy before placement in the DCDB. The primary use of the digital profile data is to drive a WILD OR-1 or Gigas-Zeiss GZ-1 to produce an orthophoto.

Lastly, DCASS forms a DEM from digitally-encoded vector contour data. Stereoplotters, interfaced with three-axis digital recording modules, are used to collect vector contour data while the instruments are being used for 1:24000-scale photogrammetric stereocompilation. During the acquisition phase, the contours are assigned elevation values (attributes). The vector contour data are processed into scan lines and the elevation matrix is formed using a bilinear interpolation between the intersections of scan lines with the contour vectors. DCASS was initially developed to perform automated map compilation. Its primary goal is to produce color separates for map reproduction.

The methods used for determining vertical accuracy differ with the collection method. With the GPM2, an RMSE value is derived from a weighted solution of the relative elevation differences between extrapolated patch joins and the relative elevation difference between coincident points in the overlap area of the two stereomodels covering a quadrangle. The RMSE of the elevation data derived from the manual profiling and DCASS systems, however, is computed by comparing known ground vertical control elevations for a minimum of ten (10) discrete image points to the linearly interpolated DEM elevation points.

ERROR DETECTION AND VERIFICATION

Most elevation errors are introduced during the data acquisition phase. Depending upon the particular recording device and the operating procedures that are used for data capture, elevation errors may be introduced into the DEM data in a variety of ways.

The GPM2 uses an automated image correlation technique to accomplish stereorestitution, and there are natural terrain conditions under which the correlator cannot derive precise elevations. Additionally, the ground resolution of the elevation data from the GPM2 is finer than the resolution of the resampled data within the NDCDB, and the subsequent regridding, interpolating, and smoothing of the data tends to generalize the terrain topology.

The manual profiling technique of orthophoto generation uses procedures that may introduce DEM elevation errors in another manner. The width of the scanning slot, and the associated digital profile spacing, is typically larger than the sampling interval along profiles. This disparity in the bidirectional ground spacing of elevation data, while justified in terms of time requirements and orthophoto image quality, causes loss of topologic detail. Local features falling between scan lines will not be represented.

Another area where errors can be introduced when using the manual profiling technique is associated with the instrument operator. In profiling, the operator must manually keep the "floating dot" on the surface of the stereomodel. Optometric studies indicate that there is systematic operator tendency to profile above ground level while scanning downhill, and below ground level while scanning uphill. The normal data collection procedure of alternating the profile direction thus tends to introduce an alternating data error. Graphics produced from this data exhibit a herringbone pattern, particularly in steep terrain (Brunson and Olsen, 1978). The operator's reaction time to differential changes in slope and natural terrain features may also introduce incorrect elevation values. The elevation data from the manual profiling systems tend to be more generalized then the GPM2 data, due to the higher degree of operator generalization of the terrain during the recording process and the sparser sampling intervals.

With DCASS, vector contours are compiled by use of standard photogrammetric map compilation practices, and elevation grids are then derived from the contours. Therefore, the accuracy of the DEM data is dependent on the cartographer's ability to accurately define the contours and the gridding algorithm that is used to convert the contours to an elevation matrix. Vertical accuracy tests using 90 to 220 points per quadrangle yield average elevation errors of less than one-half the contour interval (Boyko, 1982).

In all the above data acquisition systems, the photogrammetric procedures that are used in establishing control necessary for a proper orientation of the models to the ground may introduce errors or distortions into the DEM. The proper interior, relative, and absolute orientations are necessary in order to minimize errors in model elevation datum and scale.

The current NMD collection techniques do not constrain DEM's to known planimetric topographic features such as ridge-lines, water courses, and transportation networks. The geomorphic fidelity of these features is many times distorted or possibly lost due to either the raw data collection interval or the flattening effects of subsequent interpolation.No matter which DEM production procedure is used, elevation errors, if uncorrected, result in DEM's that are physically incorrect portrayals of the terrain surface.

Quality control procedures for detection and verification of errors have been developed which cover many phases of data production, from initial data collection to public distribution. The most common forms of quality control procedures make use of diagnostic programs and verification graphics at various checkpoints within the production processes. These include isometric and contour plots, color image displays, and programs which output error logs or symbol-encoded error plots.

Verification graphics derived from DEM data can be used for a visual comparison with existing forms of line manuscripts. User-supplied transformation parameters, in the form of desired geographic projection, plotting scales, viewing angles, and map coordinate bounds, are used in conjunction with the DEM data to produce verification graphics. Plotting hardware includes electrostatic printers, pen plotters, and cathode ray tube display devices. Detection techniques which use diagnostic printouts and error symbol plots have evolved as cost effective methods.

NMD is currently developing another method of DEM quality control which makes use of a color image-display system to accentuate certain types of error signatures by color banding, shaded relief, and anaglyphic stereo. This type of quality control is being used on a developmental basis to check data files input to and output from NMD digital data bases. Ultimately, it will be used to preview, and possibly edit, DEM data prior to data base entry and (or) distribution.

EDITING

At NMD, DEM data can be edited at two stages within the production network: the raw data acquisition stage, and the regridded DCDB stage. The decision to edit a DEM is based on two criteria: (1) the model is observed to contain a significant amount of topographic discontinuities (steep slopes, water, etc.); or (2) the regridded DEM is found to have a large RMSE value. To prevent distortion of the DEM, the data should be edited at the input stage and not after the data have been regridded to a coarser resolution than that collected. However, due to the large volume of data contained in raw GPM2 models, this is not always the most cost effective approach.

Because the GPM2 has been the primary source of the USGS DEM's the concentration of effort has been directed toward development of techniques to edit the raw elevation data produced by the GPM2. The GPM2 uses an automated stereoimage correlation technique to derive terrain elevation values. Perfect image correlation is not always possible due to a number of factors. The presence of such features as steep terrain (cliffs and overhangs), shadows, forests, ice and snow fields, and water bodies can cause the GPM2 to obtain incorrect elevation values.

While the GPM2 cannot always derive correct elevations over certain types of topographic features, the correlation of water areas presents the most significant problem. This problem is encountered when the GPM2 is attempting to correlate images of water bodies and other terrain features where corresponding image points cannot be found. Consequently erroneous elevation values are often assigned to grid points that fall within water boundaries. The result is a physically incorrect representation of the terrain surface. Software has been developed to modify DEM's that have water bodies. The DEM can be modified spatially by processing the digital elevation data through this DEM water edit software to replace the erroneous elevations with an externally derived value for the water surface. A DEM containing a significant amount of water coverage will often have a large RMSE value. A number of DEM's have been modified with this software to date, and the RMSE of each has been reduced significantly to permit the DEM to be entered into the DCDB (Troup, 1982).

Various types of mathematical filters may be applied to edit DEM's. Experience indicates that such filters, when applied to the DCDB DEM files, can remove certain types of errors up to a threshold of ± 8 meters without impacting the overall accuracy of the model. Discontinuities exceeding that threshold are evidence of possible errors in correlation due to image quality or terrain conditions that must be addressed at the raw data stage. For example, residuals derived from GPM2 elevation data are known to be greater along patch edges than inside patches (Allam, 1978). These residuals affect patch and model joins and are detectable in the final regridded DEM's as sudden changes in elevations parallel to the x and y axes of the patch data.

Another type of error detection and correction software was developed to determine errors in GPM2 generated elevations at the raw data stage (Computer Sciences Corporation, 1978). Elevations within each patch are intrarelated due to smoothing performed by the electronic and optical systems of the GPM2 (Collins, 1981). Each patch, however, is generated independently. The error detection software therefore considers each patch as a single entity which is analyzed with respect to its neighboring patches. The terrain data are assumed to represent a smoothly varying surface, i.e., the transition between patches should not be abrupt. The detection software applies several statistical tests, e.g., mean difference and slope and intercept, to evaluate patch joins and flag discontinuities in the surface. The test results, considered as a whole, provide an indication of the types of edits that can be made to improve the model. The error correction software also operates on entire patches. It permits raising or lowering and tipping or tilting of patches to bring them into better conformance with the surrounding terrain. Determining the proper corrective actions is a complex process requiring the use of subjective judgment on the part of the editor. Examination and interpretation of the source photography, orthophotoprint, or existing published line map can help in this decisionmaking process (Computer Sciences Corporation, 1978).

CONCLUSION

DEM production at the USGS has evolved from the orthophotomapping program. The orthophoto and DEM programs are tightly coupled, as reflected by project authorizations. Currently, there are three elevation data acquisition systems in use by the NMD. The primary product of two of these systems, the GPM2 and manual profiling, is an orthophotograph. The third system, DCASS, was developed to automate the map compilation process; its primary product is a set of final color separates. In all three cases, DEM's are derivative byproducts.

Raw elevation data sets which are generated by NMD are validated using a variety of graphics and diagnostic programs that are designed primarily to detect gross errors. DEM data can be edited or smoothed at several stages in the production cycle. Currently, the only edits which are routinely performed involve the correction of water surfaces and the removal of gross errors. Raw elevation data sets are post-processed into a standard format, tested for vertical accuracy, and archived in the DCDB.

DEM's are separated by the NMD into three levels. Virtually all of the DEM's which have been collected to date are considered to be level 1 because of the limited amount of editing performed. A long-term goal of the National Mapping Program is to provide digital cartographic data commensurate with the inherent accuracy of the 1:24,000-scale topographic maps. DEM's produced to the current standards (7-meter vertical RMSE) from high-altiitude photographs will not satisfy vertical National Map Accuracy Standards for contour intervals of less than 80 feet.* Therefore, the data currently resident in the DEM data base must be viewed as an interim product.

The USGS has archived thousands of stable-base film positive contour separates, and long-term expectations are to produce DEM's from automated sensing, measurement, classification, and processing of the data contained in these manuscripts. Currently, NMD is developing a system to produce DEM data from the contour separates using automated techniques. This in-house system is anticipated to be in production by the mid-1980's. These methods are expected to produce level 2 data directly. The production of level 3 data is considered a desirable end goal, and will be developed in the future.

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*Based on statistics, the contour interval that can be achieved from a given set of data is 3.3 times the RMSE of that data, i.e., a 7 meter RMSE is roughly equivalent to an 80 foot contour interval.

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THE COLLECTION AND ANALYSIS OF NATURAL RESOURCE DATA IN THE 1980s

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ABSTRACT

In an era of increasing need for the discovery and development of our natural resources, the U.S. Geological Survey has an important role to play. The accomplishment of this role will require improved efficiencies in the storage, manipulation, and presentation of data, but that task will be complicated by current personnel and budget constraints. Increasing reliance upon technological innovations, therefore, will be essential. The Survey is already providing topographic map information in digital form and exploring means of automating more of the mapping process. Computer modeling has become a common tool of Survey geologists and hydrologists. Now these scientists are working with Survey cartographers to combine data bases in order to efficiently produce comprehensive compilations of earth science data. The use of computer graphics in all forms has also increased and is now commonly used for the analysis and presentation of data required in policy decisions. Because the Survey anticipates an increasing demand for natural resource information in the future and recognizes the many advantages of recent technical advances, increased emphasis will be placed on the use of telecommunications, automated data collection, computer-based analysis, computer graphics, and automated mapping in the remaining years of this decade.

INTRODUCTION

The United States faces many difficult resource and land management issues involving: energy and mineral exploration and prudent development, assessment of the Nation's water resources (quality and quantity), and natural hazards examination, among others. Maps and mapping have always played an important role in dealing with issues of this type and will continue to serve in a vital capacity in the future. As we near the end of this century, several problems face the mapmaker, the earth scientist, and the land manager who would meet the challenges of providing data in these vital areas:

- Location of undiscovered resources requires the application of sophisticated techniques commonly requiring the processing of large amounts of data.

Also, this will require a look at lands that are not altogether accessible--wilderness areas, OCS, etc.

- Increasing competition for, and public discussion about, the most appropriate use of land and resources require detailed consideration of the economic and environmental impacts of proposed actions, i.e., to leave open for exploration and development or set aside.

- Concern about the consequences of action or lack of action requires that analysis be done completely and quickly. This necessitates extensive modeling of natural process and proposed action. Fortunately, technology has now provided the scientists and the decisionmaker with a vast array of powerful tools to aid the process considerably.

U.S. GEOLOGICAL SURVEY ROLE

In order to provide a framework for a discussion related to management of natural resource data and the application of computer data bases and automated cartography, it might be helpful to review briefly the mission of the Geological Survey.

The Geological Survey was established in 1879 and charged with the responsibility for the "classification of public lands and examination of the geological structure, mineral resources, and products of the national domain." Over the years the evolution of the earth sciences, the need to carefully manage the Nation's nonrenewable resources and to find new sources of critical energy and mineral commodities, and mounting concern over man's impact on the environment have added numerous other duties including geographic research, hazards duties, topographic and geologic mapping, and water resources assessments. The Survey is an impartial research agency that gathers, interprets, and distributes data in order to advance scientific knowledge of the Earth so that managerial decisions related to natural resources can be based on objective information.

To meet the ever increasing needs for the more sophisticated uses of our data, scientists at the Geological Survey are embracing computer assisted cartography as an essential element of their work. Also, sophisticated computer analysis is becoming a common practice among those who use our information (inside the Geological Survey as well as outside).

As the primary Federal earth science, research, and fact-gathering agency, the Geological Survey provides information for sound planning and decisionmaking as it has for many years. Now much of that information is provided on computer tapes. The computer data bases of the Survey must meet the needs of many as a source of information and to support analysis, and the cartographic data base should also provide the connecting link to permit the integration of many disparate data sets. In addition, as a major mapping agency we must assure that data bases can be used to enhance our capability and capacity to prepare and revise maps.

THE CHALLENGE OF THE 1980's

As both a producer and a user of cartographic and earth science data, the Geological Survey, like many other agencies, faces major challenges to establish and manage these data base and to develop standards to allow easy access and convenient use. Already, there are large data bases in existence and more are on the way. In addition, we are not the only organization to collect and store data.

To assure that the cartographic, geologic, hydrologic, and other related information can be readily used to produce comprehensive insights required by today's researchers and decisionmakers, the Geological Survey and other mapping organizations are obligated to insure that high standards of accuracy and integrity are maintained in the design, development, and management of these data bases. We must provide: the basic foundation to enable the integration of many data types and sources, and truly multiple purpose data bases that will serve all.

In recognization of our obligations in these areas, we have set out to:

- Manage our internal data bases in a consistent, but not oppressive, way. We may now have as many as 250 separate data bases which require some oversight. We have had a Data Base Administrator for some time, and a great deal of progress has been made. We are now reorganizing our computer operations to insure additional oversight for the Bureau's information systems.

- Develop standards for earth science information that can be used both internally as well as externally.

  The Geological Survey is carrying out a leadership role in the development of standards for earth science data through a memorandum of understanding with the Bureau of Standards. This is especially appropriate considering the Survey's role as the Nation's mapper, which provides that core cartographic data set to which all others must tie. Committees have been established within the Survey and the Department of the Interior to examine and review current activities and develop recommendations to the Bureau of Standards for Federal standards on earth science data. The first set of standards to go through this process have just been published as Circular 878-A: Codes for the Identification of Hydrologic Units in the United States and the Caribbean Outlying Areas. In addition, the Survey has supported the establishment of a National Committee on Digital Cartographic Standards under the auspices of the American Congress on Surveying and Mapping. These activities represent the beginning stages of an ongoing effort to provide the necessary foundation to insure the usefulness and applicability of automated earth science data now and in the future.

None of us has the power to legislate standards--hopefully we can be convincing regarding the benefits.

- Properly design the data base to assure multi-purpose use.

- Insure user input into all decisions related to data input, etc.

DATA BASES (EXAMPLES)

Digital Cartographic Data:
Recognizing the essential role of cartographic data for resource studies and considering our responsibilities as the civilian land mapping organization, we have undertaken the development of a national digital cartographic data base. This activity encompasses all of the complexities, concerns, and obligations discussed earlier. To serve national needs, we must insure that our data base:

- Provides data that people need.
- Interfaces with almost every data bases around (proved the link).
- Contains enough information for complete analysis.
- Is easily accessible.
- Can be developed at a reasonable cost.
- Accommodates data from others.
- Support the mapping process.

The National Digital Cartographic Data Base encompassses planimetric and elevation data from the standard topographic maps of the Survey. The principal categories of planimetric data being included are: the Public Land Survey System; county, State, and Federal boundaries, highways, roads, trails, and rivers, streams, and water bodies. The primary scale of collection is 1:24,000, but pilot projects are examining the efficiency of data collection at other scales. Elevation data are being collected at 1:24,000-scale, but the Survey is also distributing elevation data at 1:250,000-scale collected by the Defense Mapping Agency. One of the most notable achievements of the Survey's digital cartography program is the completion of a national series of maps at 1:2,000,000-scale.

In response to the need for digital cartographic data suitable for applications at regional or national scales, the Survey has introduced a data base at the 1:2,000,000-scale. This data base was constructed from the general reference maps of The National Atlas of the United States of America. It includes political boundaries (State and county level), Federal lands, transportation networks (roads and railroads), and hydrographic features (streams and water bodies). The source materials were updated immediately before the digitizing phase, thus providing the most current information available.

Other forms of cartographic and geographic data are also becoming available in digital form. Land use and land cover data at 1:250,000-scale (some at 1;100,000-scale) are being produced along with digital data on county boundaries, census subdivisions, hydrologic units, and Federal lands. These will provide a baseline of information useful to land use planners and resource managers. Also, a Geographic Names Information System, incorporating over 2,000,000 names of geographic places and features in the United States, has been completed. These names have been extracted from the largest scale map covering an area and, in addition to serving Federal, State, and local requirements, are playing a role in the automation of the mapping process.

Not only are digital cartographic data important to the analytical functions of the Survey and the earth science community, but they are essential to the automation of the mapping process. Automation is playing an increasing role in the Survey's mapping activities. A major development has been the collection of digital information directly during the stereocompilation process. Research and development efforts have led to the implementation of a digital cartographic software system that has proven to be very cost-effective. The data collection subsystem consists of stereoplotter instruments fitted with digitizing units. Each station is equipped with voice data entry systems to improve operator efficiency. This system has led to improved efficiencies in the map production process in addition to collecting certain categories of digital data. Ongoing research is directed towards the automated production of map separates and the development of effective means of digital map revision.

WATER RESOURCES APPLICATIONS

The Geological Survey has accumulated extensive data bases describing the water resources of the United States. Such data bases are essential for the effective monitoring of trends in water quality and availability. Programs like the National Stream Quality Accounting Network provide the information to account for the quality and quantity of water moving within the United States, to develop a large-scale picture of how stream quality varies from place to place, and to detect changes in stream quality over time. A crucial role is played by the Water Data Storage and Retrieval System (WATSTORE), which includes data on surface and ground water supplies and quality, chemical analyses, peak flows, and water use. This data base serves numerous State, local, private, and Federal agencies in their efforts to develop and manage water resources. These hydrologic data are used not only in determining the adequacy of water supplies but also in designing dams, bridges, and flood control projects, in allocating irrigation projects, in locating sources of pollution, and in planning for energy development.

Columbia River Irrigation Project:
A recent project that illustrates the importance of such hydrologic information as well as the value of integrating different types of data is an irrigation planning project for the Columbia River. The Umatilla River basin in Oregon was analyzed in a cooperative effort with the U.S. Army Corps of Engineers to determine its potential for irrigation.

Irrigation demand results in the largest consumptive use of Columbia River water, so it must be managed both to maximize agricultural benefits and to insure the wisest use of water and power supplies. Hydropower generation, in particular, is most adversely affected by irrigation development. The development of 10,000 acres of irrigation causes an average annual loss of $310,000 of electrical energy. Future irrigation development must take place in areas where the loss of power revenues is more than compensated for by the benefits derived from the new irrigation.

To develop a solution to this problem, several types of data were required. Pumping plant data were used to describe the location and efficiency of pumps to provide the water. Detailed soil survey information was used to identify soil irrigability ratings. Elevation data were required to compute slope information needed in the irrigability potential study and to provide estimates of the potential energy consumption for irrigation. In addition, information on land cover and land ownership was utilized to conduct the irrigation potential analyses.

These data were integrated in a complex analytical model that recognized the spatial variations inherent in the problem. A composite mapping technique was applied that permitted the variables to be precisely registered to a base map and overlaid. The composite map provides ratings of development potential based on the physical characteristics of the landscape, the economic impact of energy costs, and government restrictions prohibiting irrigation. The maps produced in this study provide a starting point for planning future regional uses of land, water, and power resources. From this starting point, more cost-effective field studies will be possible, and more resource-efficient water development decisions can be made.

GEOLOGIC APPLICATIONS

Computerized Resources Information Bank:
The extensive work of the Geological Survey in the collection and analysis of data in support of energy and mineral discovery and development has led to the establishment of several major data base systems. One of the earliest of these was the Computerized Resources Information Bank,

which still provides a means for rapidly organizing, summarizing, and displaying information on mineral resources. One of the more recent developments is the National Coal Resources Data System, which provides for on-line analyses of data relating to the location, quantity, and physical and chemical characteristics of coal. These systems enable a wide range of studies to be conducted that extend our knowledge of energy and mineral resources more rapidly and more completely than would otherwise be possible. The Survey also manages the National Earthquake Information Service, which utilizes digital data recording devices all over the world to gather and analyze seismic events. The resulting data base of seismic activity provides a valuable international tool for geophysical research.

National Coal Resources Data System:
The National Coal Resources Data System incorporates resource and chemical data on an areal basis (county, township, or coal field) and point source data including field observations and drill-hole logs. Such variables as bed thickness, name, moisture, ash, sulfur, major-, minor-, and trace-element content, heat value, and characteristics of overburden, roof, and floor rocks. The system is designed to incorporate data from many sources including the Geological Survey, the Department of Energy, State geologic agencies, and private coal companies. This flexibility is a key feature of the system that will allow for data update through ongoing field and mining activities to permit reassessment of the resource estimates based on the most current information.

The system is used to calculate coal resources and quality for any geographic area, coal bed, or series of coal beds, to calculate and discriminate overburden categories, and to locate, through computer analysis, the more desirable portions of a coal deposit. The system can reproduce the basic data as maps using digital plotters. It derives and plots structure sections and structure contours, as well as ispoach maps for any analyzed chemical element and ratio maps between any desired characteristics. These capabilities mean that the National Coal Resources Data System has a crucial role in the identification and asessment of energy resources from the country.

Alaska Minerals Resource Appraisal Program:
The need for better information on mineral resources has led to the establishment of programs such as the Alaska Minerals Resource Appraisal Program. A recent project under that program involved the use of digital image analysis techniques to develop and apply a conceptual model of porphyry-type copper mineralization.

The 1° by 3° Nabesna quadrangle in east-central Alaska was selected as the study area because copper mineralization is known to occur in the area, and a large amount of data was available. A wide range of data was utilized, including geophysical, geochemical, topographic, geologic, and Landsat multispectral scanner data. All the data were registered to a map base and integrated into a raster data base.

Various processing techniques were applied to the data in order, first to identify relationships among the variables by correlation and second to develop quantitative weights for a mineral potential model. The resultant model contained 10 parameters that could be applied to the data base to quantify the likelihood of mineralization.

The applications of the model resulted in the identification of three areas most likely to contain porphyry copper mineralization. Two of the areas are known occurrences of mineralization, but the third case, which had the highest potential rating, had been unknown until this study. Field studies in August 1981 confirmed that all three areas identified by the model have significant copper potential.

CONCLUSION

We are faced with challenging scientific, data handling, and management problems if we are to fully meet the identified needs at reasonable cost. As the information revolution leads to the creation of more and larger data bases with an ever-increasing body of hardware and software tools for their use, care must be exercised. It is important to remember that the primary motivation for automation data collection and analysis was to use the tremendous power of the computer to integrate and synthesize large quantities of disparate data. If each data base is allowed to develop in isolation, the ability to integrate data will be limited. Problems are emerging that require the use of data from many different data bases. The time to address these problems is now, during the creation of these data bases. It is necessary to plan and develop systems so that the interchange of data among them is facilitated and not hindered. As part of this process, it is necessary to develop standards for computer-readable data to insure that data exchange is efficient. This is not an easy task considering the pressure to move-out smartly and reduce expenditures.

A NATIONAL PROGRAM FOR DIGITAL CARTOGRAPHY

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ABSTRACT

Since 1977, the U.S. Geological Survey has been planning and developing the components that are now merging into the Digital Cartography Program. This Program undertakes the development of several types of digital cartographic data to meet the needs of Federal and State agencies and other users. In addition, the data are being collected so that increasing automation of the mapping process will be possible as improvements in technology occur. It is expected that the Program will be supported through a revolving fund on a self-sustaining basis. For the Program to be effective, it is essential that the products developed address the needs of the user community and are easily usable. To insure this, various coordination mechanisms are in operation to provide feedback on the suitability of the products. There are presently four main types of products available to the public. An active research and development program is also underway to examine new products and more efficient means of data production.

INTRODUCTION

Digital cartography has many faces. For some it is the use of automated techniques to produce a finished map from a digital data base. For others it is the automation of the mapping process to achieve greater efficiences of production. It can mean the availability of base information in digital form that permits the quick and easy preparation of thematic maps. For those in resource managing agencies, it often means the availability of digital data that enables the modeling or analysis of complex spatial problems that, in some cases, could not otherwise be undertaken. For the U.S. Geological Survey (USGS), digital cartography means all of these things. Only by recognizing and understanding the full range of uses and applications of these data can a program to construct a National Digital Cartographic Data Base be successful.

In order for the digital cartography program to be effective, USGS has established the following objectives:

- Create, manage, utilize, and distribute the national cartographic and geographic digital data base for multipurpose needs.

- Assist Geological Survey Divisions, other Federal and State agencies, and others in developing and applying spatial data.

- Coordinate digital cartographic and geographic activities and provide leadership to the Federal government in the development and application of spatial data.

- Implement digital techniques in cartographic and geographic operations.

- Establish a major capability for digital geographic and cartographic research and development.

US GEODATA

One of the major interests for the user community is the growing availability of cartographic data in digital form. Whether the data are to serve as a base for the graphic presentation of other data or to serve as the principal input for spatial analyses, digital cartographic data are valuable to a wide community of users.

The Geological Survey is now producing a number of digital cartographic products including elevation data, planimetric data, and land use and land cover data. These products are available at a variety of scales ranging from 1:24,000 to 1:250,000. The USGS has selected the term "US GeoData" to provide an overall identity to these varied products. While any individual product must still be identified by its type and scale, all digital cartographic and geographic data distributed by USGS will be known as US GeoData. This should create a more coherent image of the Digital Cartography Program and provide a clearer context for the array of products from the Geological Survey.

Information on current USGS digital products can be obtained through the National Cartographic Information Center (NCIC) headquartered in Reston, Virginia. They can provide information on the specific coverage of available data and their costs. User guides are available that describe the data content, formats, and coding schemes. NCIC will also handle orders for any categories of data that are available.

Current digital products can be summarized under three headings:

1. Geographic Names Information

2. Digital Elevation Models (DEMs)
   a. 1:24,000-scale DEM data
   b. 1:250,000-scale Defense Mapping Agency digital terrain data

3. Digital Line Graphs (DLGs)
   a. 1:24,000-scale topographic series
   b. 1:250,000-scale land use and land cover series
   c. 1:2,000,000-scale planimetric information

The creation of these products reflects the present capabilities of USGS for data production and the expressed requirements of major users, especially Federal agencies. In the future, the list of products can be expected to grow and change as capabilities develop and as the requirements for digital cartographic data expand. Even at this present level, the products represent a considerable base of information for users that is worth examining in more detail. However, today, particular attention should be given to a new digital cartographic data base covering the entire Nation at 1:2,000,000 scale.

1:2,000,000-SCALE DATA BASE

The Geological Survey, in responding to increasing user needs for up-to-date cartographic data and products on a nationwide basis, is introducing a digital cartographic data base at 1:2,000,000 scale. A major emphasis of the USGS has been the development of a digital cartography program applying automated techniques to the cartographic process. This approach offers the attractive features of reduced manual effort, quick response, high precision, and the versatility to generate products of various scales, projections, feature combinations, and output media. Until now, there has not been a suitable data set available for user applications at a regional or national scale in the United States.

Existing digital cartographic data bases that include the United States are the CIA's World Data Bank I and World Data Bank II, and the DIMECO files. Some of the limitations associated with these data sets are the very small scale of the source material used for the original digitization, the limited range of features digitized, the lack of currency of information, inaccurate source documents, and the limited flexibility for merging these files with thematic data available in digital form from various organizations.

Using World Data Bank II as an example, source documents were digitized at scales of 1:1,000,000 to 1:4,000,000; digitizing was performed from 1973 through 1977; and only coastlines, islands, lakes, rivers, and international and State boundaries are available for the United States. Past experience with these data sets has shown that, while they most likely met the objectives for which they were designed, their content is not sufficiently comprehensive for many common cartographic applications.

The current 1:2,000,000-scale digital data base is intended to address several of these shortcomings. The cartographic source materials used for digitizing (the general reference maps of The National Atlas of the United States of America) are at a scale of 1:2,000,000--the only exception being the Alaska drainage manuscript which were originally compiled at 1:1,000,000. The content of the data base includes political boundaries (State and county level), Federal lands, transportation networks (roads and railroads), hydrographic features (streams and water bodies), and populated places. The National Atlas source materials were updated immediately before the digitizing phase, thus providing the most current information available. The inclusion of more data categories and the more accurate digitization has also resulted in a larger data base. For comparison, World Data Bank I contained about 20,000 points and World Data Bank II had 1.5 million points to cover the entire world, while the 1:2,000,000-scale data base has some 15 million points to cover the United States.

These data were digitized using digital line graph procedures. The term "digital line graph" (DLG) has been selected to describe planimetric map data collected by USGS. All these data are digitized in a topologically complete, arc-node structure; identifying beginning and ending nodes and areas left and right. This procedure avoids duplicate digitizing and permits the use of software to perform topological verification resulting in more consistent and accurate data.

The classification system was designed for distinguishing not only the broad categories of map features but also the subcategories of an individual feature. The coding scheme is organized to allow the selection of specific classes of features appropriate for a map, given its scale and intended use or purpose. The various features are assigned a numerical rank based on the significance of that feature relative to other features of similar type. The evaluation of a feature's significance is based on criteria established for a given set of features and varies among different sets of features. For example, railroads are classified by annual tonnage; roads, by designation (Interstate, U.S., etc.). This will permit plotting procedures to delete features automatically, based on the relationship between the size or area of the particular features and the scale of map being produced. These 1:2,000,000-scale DLG data files represent the first full national digital data coverage with a significant improvement over World Data Bank II.

The data are available in two formats. One is a topologically structured data set which will provide a useful geographic reference system for displaying a wide range of thematic data, allow for various types of spatial analysis, and furnish a means of automatically producing patterned or solid-fill plates for reproduction. The second is a graphically oriented data set which will be compatible with the Cartographic Automatic Mapping (CAM) program. The data are distributed in a sheet format with 21 sheets covering the United States with three layers of information for each sheet: boundaries, transportation, and hydrography. The data are now available through NCIC.

RESEARCH DIRECTIONS

To maintain the viability of any major program, especially in such a high technology field, it is essential to have an ongoing research program providing new techniques, examining new technologies, and developing enhanced capabilities. The USGS is committed to a major program of research and development to expand existing capability, improve efficiency, and develop new applications.

A primary focal point is the automation of the mapping process. As budgets shrink and personnel ceilings drop, it is critical for the USGS to make the maximum use of automation. The Geological Survey is strongly committed to the incorporation of automated techniques in the mapping process. The implementation of such procedures is aimed not only at the development of digital products, but also at improved efficiencies and economies of operation. A system has been developed that permits the efficient collection of digital data directly at the stereocompilation stage. A key task now is to develop effective procedures for the digital revision of maps. Only as that process moves into production will the real efficiency of a digital cartographic data base emerge. In the area of the map finishing process, there remains considerable research and development to establish an economical system for the digital production of standard topographic maps. The time has not yet arrived where a press of a button will yield a map full of the complex levels of information expected of a topographic map.

However, it must not be forgotten that there is a growing community of users for digital cartographic data. They have a need for data today and expect it to be more accurate and expect a lot more of it than yesterday. To meet those needs as well as internal needs, it is necessary to build the data base as fast as possible. To do this, USGS is developing a major capability in raster scanning. There is a backlog of 40,000 maps in graphic form that must be addressed. This development effort is examining not just scanning techniques, but the entire production process including the attribute tagging and editing functions as well as effective quality control procedures. As the data base grows it will become one of the largest ever and will raise new problems of data management. USGS is already conducting tests of new mass-storage devices and conducting research on spatial data base management systems to insure that these facilities will be available when needed.

The Survey has recognized that, in addition to providing map base category data in graphic and digital form, there will be a growing need to interface the basic map data with other types of data, often collected by other agencies (Federal, State, and local). These data will include additional base categories, thematic data of various kinds, and administrative support data. In response to these emerging needs for data analysis and use and in an attempt to improve the current cartographic processes, the idea of an expanded data base as now conceived would serve as the source for preparation of standard graphic products, such as the 7.5-minute quadrangle maps, as well as supply customized map products to meet low volume but important needs.

Also, digital data files, both standard and customized, could be made available to various government and non-government agencies for the purpose of conducting automated geographic analysis. The National Mapping Division of the Survey is currently proposing to move in several stages from essentially manually based cartographic processes (Figure 1) to an integrated digital cartographic and geographic data base. Under the existing system, standard maps prepared by mainly manual processes are subsequently used as the source material for the digital products. We are currently proposing to expand our use of computers and associated equipment to move toward a digitally integrated system to produce standard map products, standard digital data files for geographic analysis, and customized graphic and digital products (Figure 2). Under this plan, data would be either collected directly by digital recording devices (substantially replacing fieldwork and traditional aerial photography), or converted to a digital representation as early in the cartographic processes as possible. The data, then in digital form, can be edited, checked for quality, and stored. From the digital data base the various products will be derived. One clear emerging trend is the need to be able to combine map base-category data with other data, often collected by another agency, to build a data base specific to a particular problem. A cartographic/geographic data base in digital form will present the opportunity to collect and store a great variety of data to meet these needs. These data may be collected by other agencies according to standards developed by the National Mapping Division. These standards will probably be variable, depending on data category (base categories, thematic map data, administrative type data, etc.), and all data entered into the data base will be tagged with appropriate descriptive information (source of data, accuracy, etc.). When the data are subsequently retrieved for use, the user will know the relevant characteristics of the data, and can, at that time, make the decision as to whether or not the data are suitable for his application. Obviously, it would be ideal to store only the highest quality data, but this is impracticable from a cost standpoint, and often less than perfect data is better than no data at all as long as the user is aware of the data limitations.

STANDARDS

For digital cartography to develop on a sound foundation that will effectively serve the wide range of users that are emerging, it is essential that appropriate standards be developed. Recognizing the necessity for standards, the USGS has taken a leadership role in their development as an extension of its existing responsibilities for map standards.

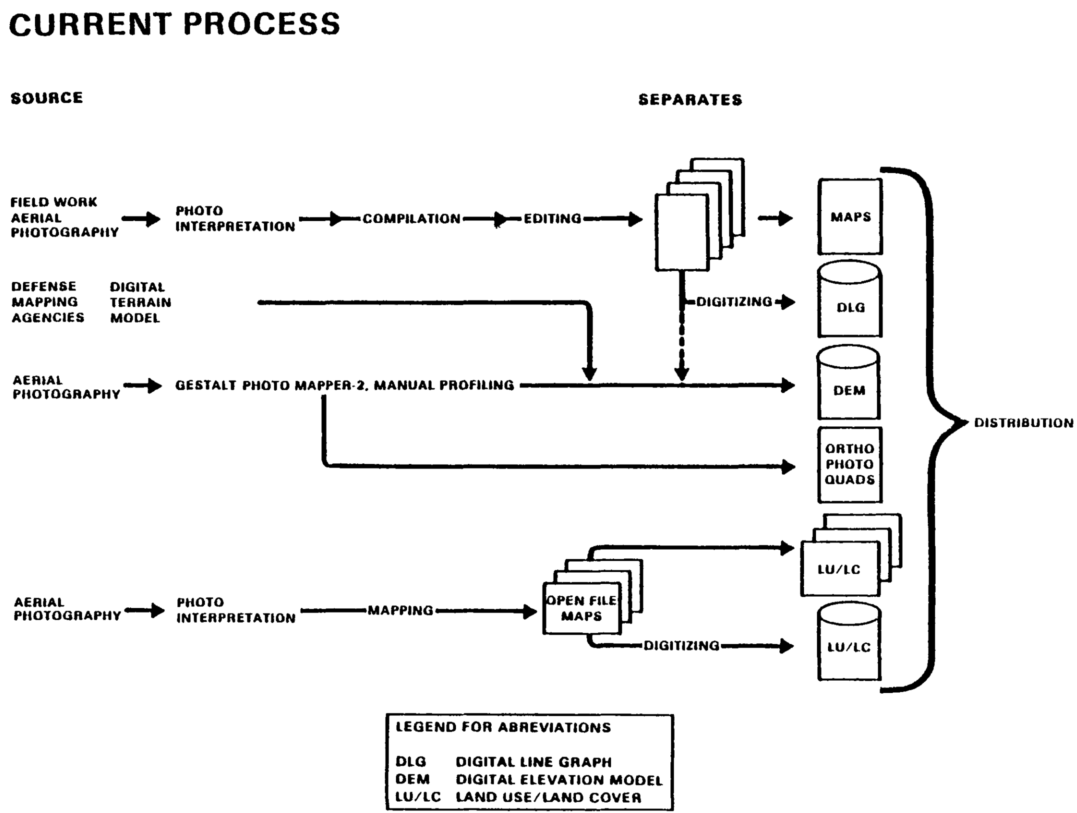

Figure 1. Current mapping process of the USGS National Mapping Division

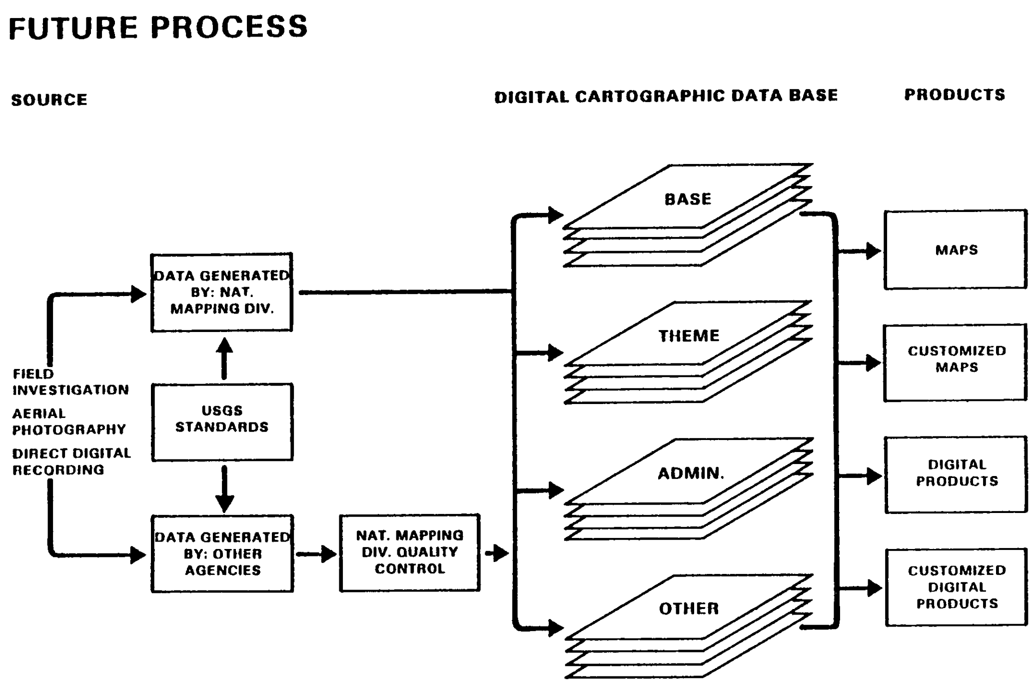

Figure 2. Proposed future mapping process of the USGS National Mapping Division

The setting of standards in digital cartography presents a number of complex problems that go far deeper into spatial data structures than the usual issues of ADP protocol and formats--issues usually discussed by computer scientists. In a very real sense the development of standards for digital cartography requires a completely fresh start in cartographic science unencumbered by current codes and specifications. The evolution of map standards and conventions over the past several hundred years is almost irrelevant in approaching the future requirements for automated geospatial analysis. The basic cartographic principles regarding accuracy, content, and currency will still be vital in understanding the new world of digital maps, but the codified standards for a graphic map do not translate directly into the computer environment.

The USGS has taken the first steps in the standardization process because the reliability and acceptance of the digital cartographic data base will thereby be enhanced. A procedure has been developed to process digital cartographic standards through the U.S. Bureau of Standards for eventual issue in the same form as many of the computer-related standards. An interagency committee has been developed at the Federal level to examine the requirements and needs of major users and to work towards the establishment of standards. The Survey has supported the establishment of the National Committee on Digital Cartographic Data Standards under the auspices of the American Congress on Surveying and Mapping with participation from across the field to coordinate the development of standards. A USGS staff section in the National Mapping Division has been established to develop and enforce standard procedures and quality control in the Divison's operations. But there is still much more to be done as the data user community develops and the role of the digital cartographic data base in relation to automated cartography and geographic information systems evolves.

CONCLUSION

The field of digital cartography is dynamic and challenging at this stage of development. The user community is steadily expanding and new applications are continually emerging that require more data and better software. It is an exciting era, and the Geological Survey is proud to play a leadership role in the field of digital cartography.

THE LASER-SCAN FASTRAK AUTOMATIC DIGITISING SYSTEM

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BIOGRAPHICAL SKETCH

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ABSTRACT

The FASTRAK system is an automatic line or edge following digitiser with the benefit of being interactive and under operator control at all times. A negative of the source document is projected onto a large console screen (0.7 metre X 1 metre) from which the operator can observe the automatic digitising process. Features to be digitised are selected by positioning a cursor under tracker ball control. After a feature has been digitised and accepted by the operator it is erased from the screen using a unique 'paint-out' facility which acts both as a completeness and accuracy check.

Since 1977 two FASTRAK systems have been used extensively by the British Ministry of Defence Mapping and Charting Establishment for digitising maps for digital radar land mass simulation. The British Ordnance Survey Office installed a FASTRAK system in 1980 and other FASTRAKS are installed in Sweden and Italy. Laser-Scan Laboratories, being the manufacturers of FASTRAK, have been operating a bureau service for a number of years at their premises in Cambridge U.K. and further details of performances achieved are given in this paper.

INTRODUCTION

The Laser-Scan FASTRAK system is an interactive automatic digitising device developed primarily for cartographic applications. Based on inhouse technology, developed over a number of years, it has proved itself to be both reliable and user friendly. In April 1982 Laser-Scan Laboratories

Limited were presented with the Queen's Award for Technological Achievement which was obtained for the development and proven cost effectiveness of FASTRAK.

Being formed in 1969 Laser-Scan has over twelve years experience in the field of computer controlled laser scanning with particular emphasis on cartographic applications. Initial work produced a laser-based line following digitiser SWEEPNIK, for use in high energy physics applications. Experience gained in this field together with that gained in the production of a high-resolution display/plotter, (Street and Woodsford 1975), and the awareness of market requirements lead to the production of FASTRAK. Its main aim being to increase the throughput of data acquisition without the disadvantages of the manual digitising table. As well as being an automatic line digitiser FASTRAK has the following additional facilities.

Interactive Control

The operator is able to intervene during the digitising process at any stage and is able to devote his skills and experience to an interpretive role in responding to particular cartographic problems.

Feature Selection

The operator can select only the features which are required to be digitised and has complete control over the order of selection.

Feature Coding

By means of the control console the operator can classify and code features at the intial capture stage. This is achieved very simply by selecting the appropriate function button at the time of initial alignment. The numbering of features within a particular feature code is done automatically the incremental steps being previously selected by the operator, thus being particularly useful in, for example, the coding of contours.

Erasure of Captured Features

After a feature has been captured the operator has the facility to erase this feature from the console screen. This process is actually controlled by the captured digital information of that feature so that it acts as both an accuracy and completeness check. This process is particularly useful when one is digitising dense data and thus prevents double digitising or feature omissions. The details of this 'paint-out' facility are described in more detail in the next section.

Multiple Data Capture Sessions

Again using the 'paint-out' facility the operator is able to continue jobs which are only partially completed. After initial registration with the source negative all the previously captured data is erased from the screen and the operator continues in the normal fashion.

Hard Copy Plots

Integral to the FASTRAK system is the facility to produce a hard copy plot onto microfiche sized (148 mm x 105 mm) film. Development of these plots is by means of a simple desk-top machine providing permanent hard copy with clear lines on a dark background, ideal for reproduction and check plots.

Editing Facilities

Previously captured data can be drawn directly onto the large console screen and FASTRAK can be operated in its 'HRD1' mode. (Woodsford 1976). The screen has a resolution of some 3500 X 5000 lines with an addressability to within one tenth of a line width. By use of a tracker ball, completely general refresh images can be produced, features selected and erased.

Large Screen

The large console screen allows the operator to view and digitise the source document at actual size or indeed magnified in the majority of cases. When used in the HRD-1 mode the operator is therefore not faced with the continual problem of 'windowing' as presented by smaller displays.

FASTRAK HARDWARE

FASTRAK is based on laser scanning technology which is also incorporated in Laser-Scan's HRD1 display and Microfilm Laser Plotter together with an additional scanning laser and software for performing the automatic line following function.

A film negative is produced from the original source document and is projected at X10 magnification on the large console screen. The source negative itself occupies an area of 98 mm X 68 mm on a 105 mm frame so that a 40 cm X 40 cm original (e.g. a U.K. Ordnance Survey 1:1250 urban map) is reduced by a factor of 6. At this reduction factor a line width range of 0.18 mm to 1.8 mm on the original can be dealt with quite satisfactorily.

The console also houses a small close-up screen and the interactive controls which include a tracker ball, function buttons and keyboard (see Figure 1).

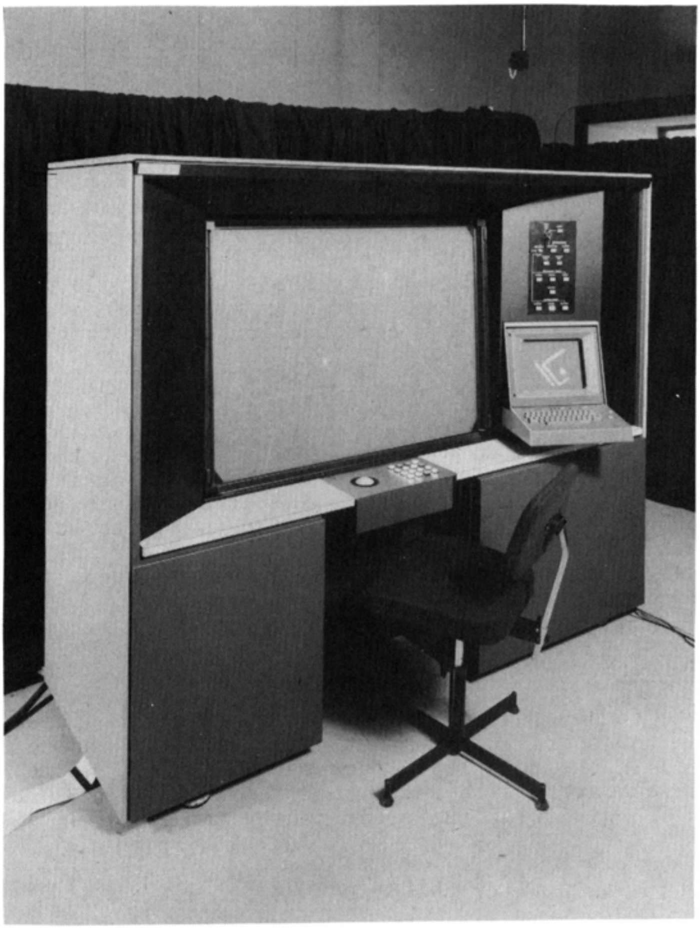

FIGURE 1

FASTRAK utilises two He-Ne lasers, one being used for the interferometric control of the beam steering mirrors and the other for the actual scanning process itself. An Argon-Ion laser is used for the 'paint-out' and plotting facility.

As can be seen from Figure 2, a reel of photochromic blue-sensitive film is sandwiched between a zone plate and the negative of the source document. The purpose of the zone plate is to present the operator with a real time trace of the digitising process by diffracting a small portion of the He-Ne digitising beam onto the screen console. It is also used for diffracting the cursor and other symbols onto the screen.

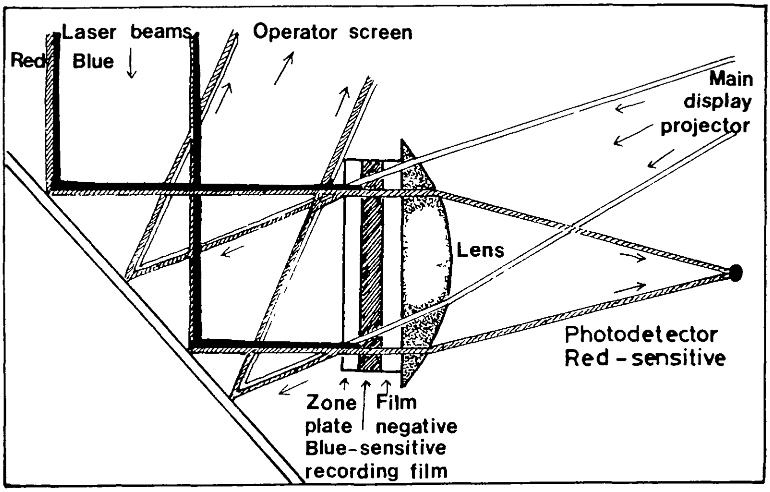

FIGURE 2

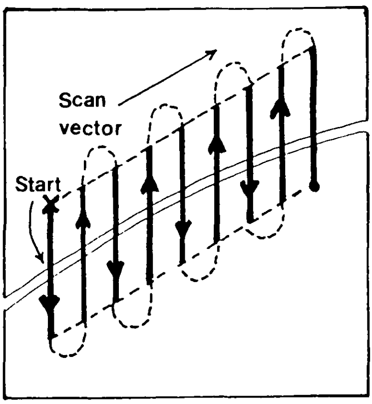

FIGURE 3

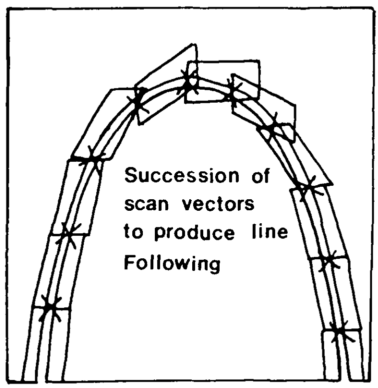

FIGURE 4

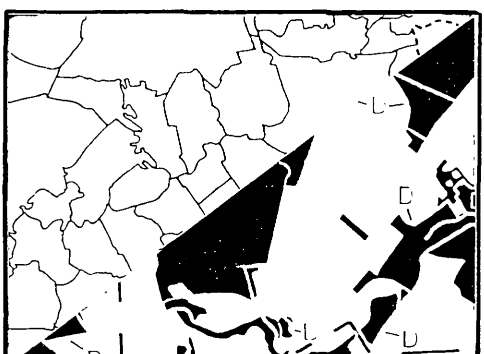

FIGURE 5

The document therefore appears to the operator as orange features on a dark background due to the filtering nature of the photochromic film.

A refresh cursor is aligned, by means of the tracker ball, onto the feature to be digitised and an initial scan vector direction is determined by the operator. Subsequent scan vectors are determined automatically by the controlling software's interpretation of data, captured from the superimposing of a local raster scan, Figure 3.

As this local raster scan traverses a line a photodetector placed behind the source negative detects the transmission of the He-Ne beam and records the width and centre co-ordinates of the line. Each scan vector contains approximately 25 or so traverses of the film at intervals of 10 or 15 microns at a speed of 500 Hertz. This data is then processed to produce a set of line elements which are subsequently compacted and used to provide the next scan vector, Figure 4 (Fulford, 1981).

Thus automatic line following proceeds until the end of the feature has been reached or the operator intervenes to stop the process. 'Paint-out' of this feature is then achieved by writing onto the photochromic film using an Argon-Ion laser which produces dark lines on the photochromic film in contact with the source negative thus erasing this feature from the operators view and preventing double digitising.

SOFTWARE CONSIDERATIONS

Control of the FASTRAK is by means of a PDP 11/45 (or upwards) or VAX 11 series computer operating under the RSX-11M or VMS operating systems respectively. The software is written in FORTRAN with machine dependent parts in assembler

The edge encounters returned by the FASTRAK hardware to the host computer can be followed directly to allow digitising of the boundaries of solid shaded areas (see later section on bureau digitising for the Forestry Commission), but more usually are immediately paired together to give line encounters having centre point and width attributes. For each scan vector the encounters that form continuous line elements are chained together. This may result in chains for lines other than that being followed being eliminated. This is achieved by using considerations of continuity and line width which results in only the chains formed by the line being followed selected. After the last scan encounter has been analysed a prediction is then made for the position and direction of the next scan vector.

Before being written to the data file held on disc the data points, representing the captured line, pass through a data compaction process. This compaction process results in a set of master points which, when joined together by straight lines, represent the line measured to within a prescribed tolerance. This tolerance is determined by a patch file selected by the operator at the commencement of a digitising session. The patch file parameters also determine the maximum distance between consecutive master points.

Feature co-ordinate data is stored in a disc file in an internal feature format (IFF). Each feature is numbered and can be sequentially or operator specified. The feature is also assigned a code defining the type of feature represented (e.g. major building, contour, river etc.) and an optional commentary for arbitrary alphanumeric information can be input by the operator. Within a file, features may be grouped into overlays by the allocation of an overlay code.

Data as captured is stored in the co-ordinate space of the FASTRAK hardware. At the start of each job, registration is achieved by measuring four corner fiducials (or more) and specifying their co-ordinates in the source co-ordinate space. The first stage of post-processing transforms the captured data to this source co-ordinate space, dealing with both distortion correction and registration. Various integrity checks are also performed (closure checks, clipping to boundaries) and statistical summaries generated. The second stage of post-processing involves translation to the required data output format, which may be a plotter drive tape or a data base format. These post-processing phases can run as background jobs whilst data capture is in progress.

An important software implementation, especially when digitising data containing a large number of nodes, is that of junction recognition. When line following the FASTRAK system is able to detect and analyse junctions. The number of arms to the particular junction is determined and a unique junction coordinate point is derived. The operator has the facility to pre-program the exit of the junction, (e.g. straight-ahead, left or right), although this choice of exit can be overridden if desired. The junction coordinates are stored together with the arm coordinates and 'paint-out' is suppressed in the region of the junction to allow 'revisiting'. When required the cursor automatically returns to the junction and the undigitised exits are followed.

FASTRAK also has the software facility for pre-guidance. The coordinates of the start of features are entered on a manual digitiser together with the relevant feature codes. When set-up in FASTRAK in the normal fashion these features are then automatically located and digitised.

It is possible to use FASTRAK to scan an entire map unattended and to post-process the resulting raster data into vector form. This technique is particularly efficient on good quality polygon maps.

SYSTEM PERFORMANCE

Performance in a cartographic production sense is dealt with in other sections of this paper. For completeness the basic parameters are given in terms of the film negative and should be related to a source document by scaling up by the photographic reduction factor.

Readable Area	:	98 mm X 68 mm on a 105 mm frame
Line Weight	:	0.030 mm to 0.3 mm
Point Accuracy	:	± 0.020 mm in either axis
Point Repeatability	:	± 0.010 mm in either axis for repeated measurements of well defined points
Line Following Rates	:	Highly convoluted lines 2.5 mm/sec Average curve 4.5 mm/sec Straight lines 5.5 mm/sec
Plotting Resolution	:	5000 X 7000 lines
Display Resolution (HRD 1 mode)	:	3500 X 5000 lines

A useful formula has been determined empirically for approximate digitising times on a variety of maps. Assuming a times five reduction, this is:

$$T = (L/12.5) + (F/720)$$

where T is the time in hours, L is the line length in metres on the original and F is the number of features.

BUREAU EXPERIENCE

Laser-Scan operates a bureau service in the U.K. for not only its FASTRAK system but also for a Microfilm Laser Plotter and LITES (Laser-Scan Interactive Editing Station). Bureau work has been carried out on the FASTRAK system for many clients and some of the more well known include:

U.K. Forestry Commission	Woodland Areas
U.K. Electricity Board	Town Maps
U.K. Gas Board	Town Maps
U.K. Experimental Cartography Unit	Contours
U.K. B.K.S. Surveys (for British Rail)	Tunnel Sections
Australian National Mapping Organisation	World Aeronautical Charts
West Germany Rhein Braun Coal Works	Contours
U.K. British Petroleum	Topographic Maps
France Institute Geographique National	Contours
Eire Petroconsultants	Contours
U.K. K Shoes	Shoe Pictures

The U.K. Forestry Commission is presently engaged in producing a Woodlands Census in which data is captured from the green overlay separations of the Ordnance Survey 1:50000 sheets. Each of the 204 sheets is marked up by the Forestry Commission with the county boundaries and woodland areas are given a classification code and may appear as solid polygons on the sheet (see Figure 5). The data is captured on FASTRAK operating in its edge following mode and appropriate coding is performed as previously described in this paper. The final output for each county is on punched card and consists of lists of woodland areas, with classification code, area in hectares and centroids. In addition woodland perimeter data is retained and used to generate check plots, on a per county per sheet basis. The throughput of 4 to 6 maps per week is geared to be in step with the Forestry Commission's programme, although the throughput could be as high as 10 to 15 maps per operator week.

Contracts for digitising 1:1250 scale Ordnance Survey urban area maps have been undertaken on FASTRAK for the Electricity and Gas Boards in the U.K. Whilst the Ordnance Survey is producing digital 1:1250 scale maps, the sheer size of the task has meant that certain areas of the U.K. have a sparse coverage in terms of digital mapping. In fact a FASTRAK system is installed at the Ordnance Survey and is presently undergoing an evaluation program for the possible future integration into their production flowline (Fraser and Woodsford 1981).

A typical map sheet used in this contract is shown in Figure 6. For the purpose of producing a detailed report on this particular contract digitisation on FASTRAK was performed by an operator completely unfamiliar with these types of maps. No particular order of digitising was pre-ordained, but experience showed, that digitising blocks of houses, complete with their fences and surrounding road edges, was the logical approach. Even for the inexperienced operator FASTRAK was obviously very much faster at capturing any form of line detail on these maps than manual digitising. The comparison was made using Laser-Scan LITES system which, although primarily a cartographic edit station, can be used as a manual digitiser. Despite the operator inexperience it was shown that FASTRAK was between 4 and 6 times faster compared to the manual method even for this type of data. Obviously when the same comparison is made for contour type data FASTRAK is very much faster (X15)

House names, numbers and any point features will take a similar time on both systems as they are manually applied. The 'paint-out' feature, described previously in this paper proved to be invaluable for this type of data capture. A typical time taken for digitising a map of this nature is six hours.

1:1,000,000 Aeronautical Charts have been digitised for NATMAP in Australia. FASTRAK was used for contours, water features and roads with point digitising for symbols. Typical times were 5 hours per separation which included edge matching and coding in addition to processing to the customer's required format.

FASTRAK has recently been used to digitise the profiles of tunnels to enable the careful monitoring of any future profile movements. B.K.S. provided 70 mm films of the tunnel using an optical arrangement which produced a pencil beam of light around the tunnel profile. It is this pencil beam which is followed and digitised by FASTRAK and throughput of 1 tunnel section per minute is readily achieved.

The profiles of shoe designs have been digitised using a recently developed raster scan software on the FASTRAK system and is undergoing further trials before general release.

M.C.E. EXPERIENCE

The British Ministry of Defence Mapping and Charting Establishment, Royal Engineers (MCE RE) produces maps and aeronautical charts at a wide variety of scales and in many designs. Involvement in cartographic automation started in the sixties and digitising methods were introduced in the early seventies. It was recognised at an early stage that the heaviest load, on a digital production system, is placed

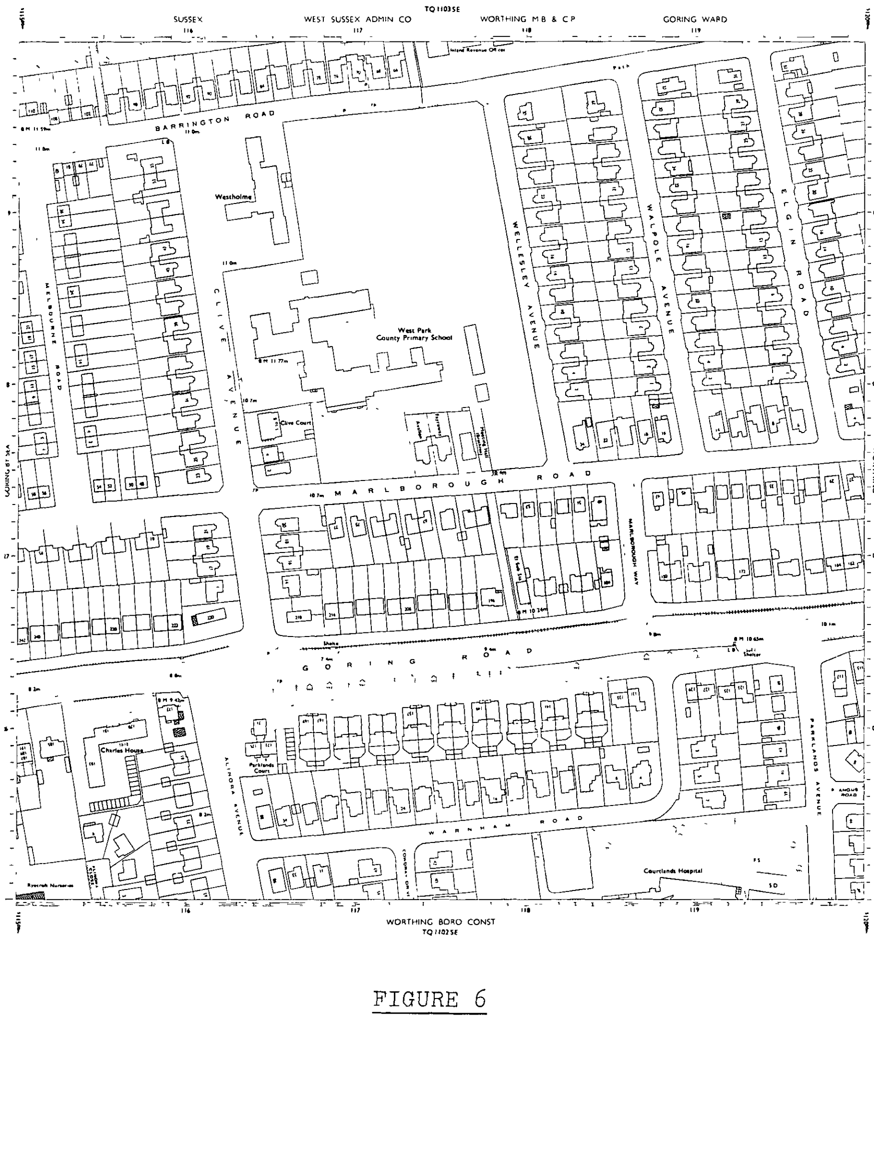
TQ 1103SE
SUSSEX
WEST SUSSEX ADMIN CO
WORTHING M B & C P
GORING WARD
BARRINGTON ROAD
Westholme
West Park
County Primary School
CLIVE AVENUE
MELBOURNE ROAD
WELLESLEY AVENUE
WALPOLE AVENUE
ELGIN ROAD
Clive Court
MARLBOROUGH ROAD
MARLBOROUGH WAY
GORING ROAD
Charles House
Parklands Court
ALINORA AVENUE
WARNHAM ROAD
PARKLANDS AVENUE
Courtlands Hospital
WORTHING BORO CONST
TQ 1102SE

FIGURE 6

on the initial data capture stage. Due to the proposed loading, on MCE digitising resources in the mid seventies, it became obvious that an improved method of data capture had to be utilised. Increased throughput was required without the basic disadvantages of the manual digitising table. Proposals were made by Laser-Scan to meet MCE's requirement and the acceptance of these proposals lead to the development of the FASTRAK system. There are presently two FASTRAKS installed at MCE both running on PDP computers together with a VAX 11/750 which controls a Laser-Scan LITES system and fix free standing digitising tables.

FASTRAK is used by MCE for two main applications. The first is in the production of maps which has necessitated the data, captured by FASTRAK from compilation manuscripts, to be re-scaled (or otherwise manipulated) for drawing on a plotter in the form of film output. The second application has its final output in digital form for use in, for example, radar flight simulators.

It was a requirement that FASTRAK could be operated by a cartographer with the minimum of specialised training. Experience showed that given a general automation background and expertise an operator can be trained on FASTRAK in approximately four weeks.

The digitising source document in both cases is a single component, this being a map colour separation in the map/chart case and a culture manuscript in the digital product requirement.

Figure 7 shows an example of a contour source document which contains 3556 cms of line, 238 individual features and resulted in 23,242 coordinate pairs captured.

The digitising time for this example was 98 minutes. Full MCE performance and operating procedures was presented in another paper (Howman and Woodsford, 1978).

SUMMARY

Experience has proved FASTRAK to be a versatile and effective automatic line following digitising system whilst still retaining the interactive facility which allows the operator to input cartographic and feature information at the vital data capture stage.

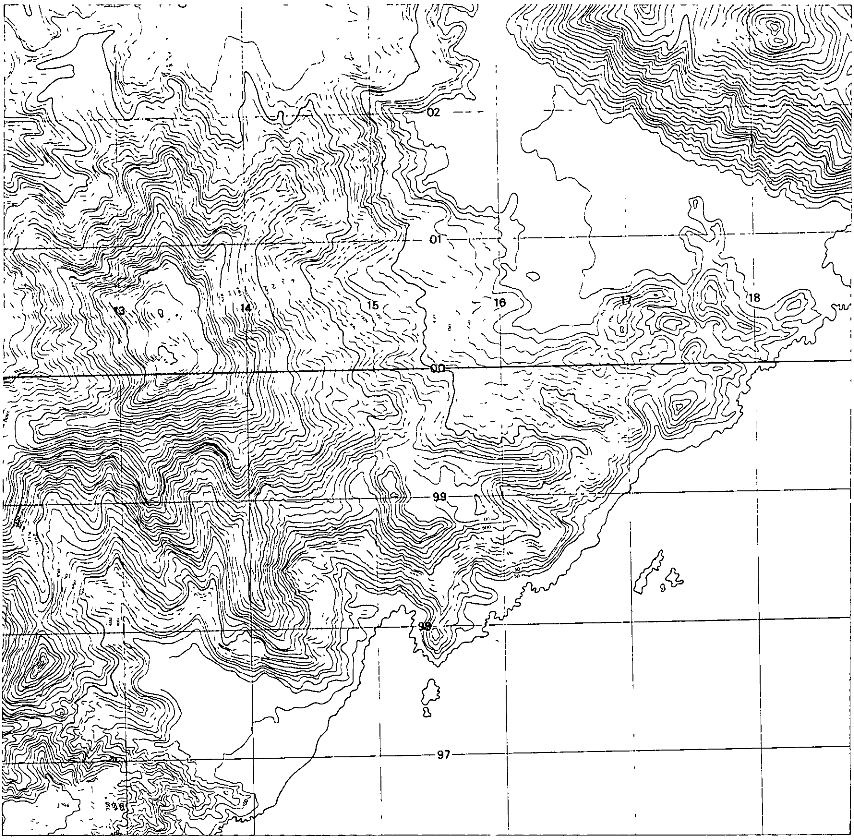

FIGURE 7

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Street. G.S.B. and Woodsford P.A., 1975, "The HRD-1 Laser Display System", ICA Commission III, Automation in Cartography.

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A PROTOTYPE GEOGRAPHIC NAMES INPUT STATION

FOR

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ABSTRACT

The collection, maintenance, and distribution of geographic place names information at the Defense Mapping Agency is accomplished through the Foreign Place Names File, an index card data base. An attempt to automate the file is currently underway, starting with the development of a prototype Geographic Names Input Station. In the short term, the station will be integrated with the gazetteer production flow and will be used to enter, process, and display Roman script foreign text information. Its more important long-term role, however, will be to serve as a testbed for the development of an all digital Foreign Place Names Information System.

THE DEFENSE MAPPING AGENCY FOREIGN PLACE NAMES FILE

The Defense Mapping Agency (DMA) collects, evaluates, and maintains names information on foreign places, as well as on undersea and extraterrestrial features. DMA supports the efforts of the Board on Geographic Names (BGN) by referring evidence for the existence and correct orthographic representation of the names to the Board for review and action, and maintains files of all BGN-approved foreign names. This names information exists as a continually expanding file which serves as a base to support the use and application of geographic names throughout the United States government, in numerous professional organizations, and for the public at large.

The file of foreign place names was established under the Department of Interior as a result of the creation of the BGN in 1890. Transferred to the Department of Defense in 1949, this collection is now called The Foreign Place Names File (FPNF). The file today includes BGN-approved names for just over 2.5 million features with primary and variant names stored on 4.5 million index cards. The file is stored in a series of power file cabinets and is organized alphabetically by country.

The principal information contained in the FPNF is the BGN-approved feature name or names, the feature designation, and locational data. Supplementary information includes a record of primary and variant names with the sources from which they were derived. Linguistic, geographic, and other pertinent notes are included as well.

Distribution of information from the FPNF has been labor-intensive and inefficient, considering currently available digital communications methods. For instance, inquiries about individual names from agencies outside DMA are handled manually by searching the index cards and responding by telephone or mail. Wider names circulation is accomplished through the publication of gazetteers in paper form. In fact, gazetteer production requirements drive (and limit) the names collection process. DMA has produced approximately 45 gazetteers since assuming the function in 1969, and until recently, the rate of production has been slow. Since 1975, only 14 gazetteers have been published. A more effective method of production was introduced in late 1980 which has increased the potential for names distribution throughout the user population by allowing DMA to produce as many as 10 or 15 gazetteers per year. However, since the current system still only allows for the addition of approximately 125,000 names per year to the data base, most gazetteers represent limited revisions. DMA is investigating state-of-the-art information processing techniques to improve the system and hopes to increase the FPNF from 2.5 million to 50 million names within a decade. Large strides in names data acquisition and processing methods must be made in order to approach this mid-range goal.

THE GEOGRAPHIC NAMES INPUT STATION

Introduction

DMA is currently sponsoring the development of a prototype Geographic Names Input Station (GNIS). The technical work is being carried out by the Department of Defense Electromagnetic Compatibility Analysis Center, Annapolis, Maryland, and supported by the IIT Research Institute (IITRI) under Contract No. F19628-80-C-0042. The US Army Engineer Topographic Laboratories (USAETL) supervises the project. The GNIS addresses basic research problems associated with the processing of foreign text, as well as immediate gazetteer production requirements. An all digital Foreign Place Names System will be developed from the FPNF, as well as from the knowledge developed during this initial work.

GNIS and the Foreign Text Problem

During the development of the GNIS, many problems common to any digital foreign text system were encountered, because the required set of alphabetic characters is not standard and exceeds both the basic English alphabet and standard American Standard Code for Information Interchange (ASCII) alphabet. Processing this information requires special techniques for data entry, storage, and display.

DMA has a large and diverse foreign language requirement. One hundred and sixteen native languages or transliterated forms, ranging from Afar to Yoruba, must be depicted in Roman script form. Over 60 percent of these languages require an extended character set with marks not found in the 26 characters (A-Z) of the English alphabet. These marks used to extend the English alphabet fall into three categories: diacritics, special characters, and special symbols. (Figure 1)

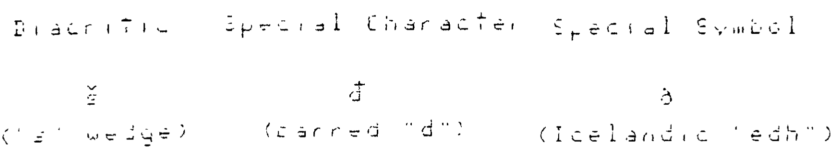

Figure 1. Sample Character Display From Matrix Printer

A diacritic is a mark that may be placed above or below an alphabetic character, but does not alter the basic character (e.g., "š"). A special character is an English alphabetic character with a superimposed mark (e.g., "đ"), and a special symbol is a non-English alphabetic character that may be used alone (e.g.,"ð"). DMA requires over seventy of these three types of marks in order to represent, as accurately as possible, the names of places and features in countries throughout the world.

An examination of the problems of input, storage, and display of the extended English alphabet text was necessary prior to selecting equipment and developing software. IITRI explored a number of options for data entry and storage and identified the keyboard as a critical element. There are two basic methods of data entry; via a standard, preprogrammed keyboard, or via an expanded, programmable keyboard. The former approach is inexpensive, and it does not require the purchase of special hardware or any keyboard programming. With the standard preprogrammed keyboard, non-Roman marks are entered using standard codes in a predefined sequence. For instance, in the Central Intelligence Agency system, an "á" is entered as follows: 1) press "A" 2) press "%" and 3) press "a". The "A" denotes the acute accent, the "%" denotes a delimiter, and the "a" represents the letter associated with the diacritic. This approach is cumbersome if a large number of diacritics and specials symbols are to be entered because an operator either must use a look-up table containing the codes or prepare a keyboard overlay. Neither solution is desirable from the human factors standpoint.

IITRI selected a terminal with an expanded, programmable keyboard for the DMA names station. The keyboard has three sets of keypads, a main keypad and two outboard keypads. The main keypad contains the basic English alphabet, while the outboard keypads contain the extended alphabetic marks. To enter an "á" the operator follows the sequence: 1) press "a" on the main keypad and 2) press "´" on the outboard keypad. This approach streamlines data entry, since diacritics may be entered with a single keystroke. The need for a look-up table is eliminated; however, the keyboard is not entirely standard and has been programmed specifically to meet DMA's needs. Data storage is in ACSII format, so an "á" would be represented as "a$a"; where the first "a" represents the letter associated with the diacritic, the "$" denotes a delimiter, and the second "a" represents the acute accent.

Attempts to standardize data storage formats for interchange among users are in the beginning stages. The International Standardization Organization (ISO) has adopted ISO 5426 "Extension of the Latin Alphabet Coded Character Set for Bibliographic Information (1980)" and proposed ISO/GIS 6937/2 "Coded Character Sets for Text Communication Part 2: Latin Alphabet and Non-Alphabet Graphic Characters." Two deficiencies of the standards, however, are their lack of agreement and failure to include all the extended English alphabet marks required by DMA. Since no inclusive standard exists, translate tables must be developed to convert one format to another.

As with data entry and storage, a number of alternative approaches exist for hard copy data display. At DMA, the final production is accomplished with a Multiset III Phototypesetting system, so the GNIS printer addresses only interim hard copy. The critical option considered for hard copy was the choice of matrix versus non-matrix printers. Non-matrix printers use a system of preformed characters cast in metal or plastic, such as a daisy wheel, type element, or thimble. These produce high quality characters, but limit the selection to those available, since the production of new preformed characters is expensive. The use of non-matrix printing is not acceptable for the DMA environment for two reasons. First, consolidated character sets meeting DMA's requirements do not exist, and second, DMA's requirements may change as new transliteration schemes are approved. Matrix printers are an attractive alternative, offering reduced print quality but much greater character flexibility. With a matrix printer, each character is formed from a matrix of cells which may be "turned-on" in any combination. Although a 7 x 9 matrix is commonly used to generate characters, DMA required an 8 x 16 matrix in order to accommodate the diacritics that must be placed above and below the English characters. A Florida Data printer was selected to satisfy this requirement. New characters may be added via a font editor as additional requirements develop. After addressing the foreign text problem, DMA was able to move towards integrating the GNIS with names production.

GNIS Hardware

The chief hardware components of the GNIS are a Plessey System 23VX with a PDP 11/23 microcomputer, an ECD Intelligent Terminal and a Houston Instruments digitizing tablet. The major computational and data storage element of the system is the Plessey PDP 11/23 micro system, using the RT-11 operating system. Mass storage consists of a 5 megabyte (MB) fixed disk and a 5 MB removable disk cartridge. A nine-track magnetic tape unit allows the user to load and transport data files. The tape drive, disk drive, and microprocessor are contained in the same compact unit which operates in a wide range of physical environments. Several hardware options are available, and the software configuration is easily upgraded.

Foreign-text entry and display are accomplished through the ECD intelligent terminal, which includes a video monitor, a microprocessor, a dual floppy disk drive, and a dot matrix printer. (Figure 2)

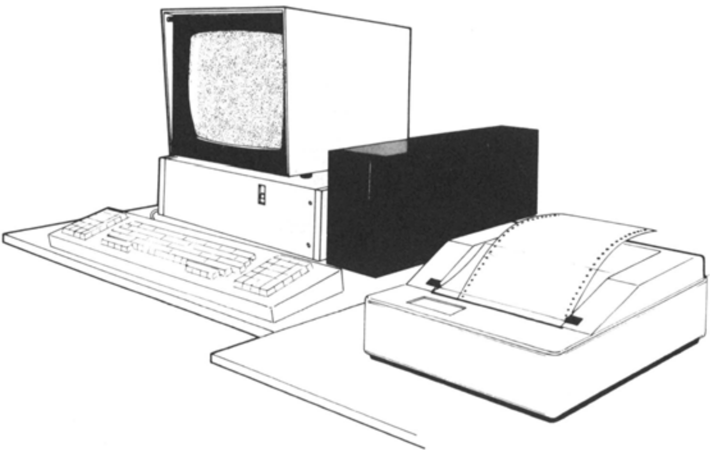

Figure 2. GNIS Work Station

The 6502 microprocessor-based intelligent terminal has a 64 kilobyte memory and 0.5 MB of floppy disk storage. The keyboard is a special configuration with two outboard keypads and programmable keys. The Florida Data dot matrix printer enables local listings of stored data. The ECD functions as the console to the PDP 11/23, as well as serving as an intelligent terminal, by means of a series of ONLINE/OFFLINE commands downloaded at appropriate intervals from the PDP 11/23. In the OFFLINE mode, the ECD operates under Translex, a display-oriented macro language that supports the many word processing features and is unique to the terminal.

The Houston Instruments digitizing tablet connects in-line by cable between the ECD and the PDP 11/23. It provides raw digitized data to the PDP 11/23 for processing.

The selection of hardware and subsequent software development was heavily influenced by the problems inherent in the digital manipulation of foreign text. Now that these problems have been solved, the system can be phased into the names production workflow.

GNIS and Gazetteer Production

As previously outlined, the current names processing system is driven by gazetteer production requirements. It is not surprising that the earliest gazetteer production was a manual process using handwritten copy and standard early printing techniques. Diacritics and special type characters were available only through special type order and were costly. The process by any standard was indeed slow. By approximately 1960, the revised process for creating gazetteers was to key names data directly from handwritten cards on to computer punch cards and store the information on magnetic tape. This revised process enabled some sorting and correction, but only uppercase alphanumeric characters could be produced on the printout, and special characters and diacritics had to be added by hand. The resulting hand-annotated printout was photographed and reduced. The photographs were used to create plates, and the gazetteer was then printed.

The current gazetteer production process makes use of the archival tapes created by the 1960's process. An archival tape without diacritics, special characters, or special marks is withdrawn from storage and translated into a format compatible with the Multiset III automated typesetter currently used by DMA. The information is processed into upper- and lowercase characters and printed on a high speed printer. The printout is then analyzed by toponymists familiar with the appropriate geographic area. If the tape is currently readable and technically complete, the printout is returned to the typesetter with the associated gazetteer along with toponymic and linguistic comments. The diacritics are then keyed by the typesetter into the digital file, and a second printout is generated. This printout depicts the diacritic as a special symbol beside the character that it affects (e.g., fore*^*t equals forêt).

The second printout is reviewed and then compared to the card file. Corrections are made by the toponymist manually on the printout. Previously unpublished feature names are manually keyed by the typesetter from file cards, and a third printout is created by the typesetter and reviewed by the toponymists. Final corrections are made by the typesetter, and the introduction and names list is printed in galley form. The galley proof is reviewed by the toponymist, minor corrections are accomplished, and the final pages are photographed. The resulting set of gazetteer negatives is forwarded for printing to the Government Printing Office. The digital file resulting from the automated typesetting may now be updated periodically to ensure that the file is current. It is important to note that this gazetteer file represents a Names Type File (NTF) only and does not include the historical or linguistic data that is associated with a primary name in the FPNF data base. The existing production system saves as much as 75 percent of the time required for manual keying, but requires extensive coordination and communication between the toponymists and the typesetters.

The prototype GNIS gazetteer production equipment provides direct contact between the toponymist and the digital data. All printout reviews of the current production system will be eliminated by the prototype system. The toponymist will review all files prior to printing. A digital file will be locally maintained for uninterrupted updating, and will serve as a primitive base for names information. It is estimated that the prototype system will reduce the project processing time by 50 percent and improve production from 125,000 to 250,000 names per year.

The GNIS has three major software programs; the NTF Tape Loader, the NTF Editor, and the NTF Tape Create. DMA currently has approximately 165 seven-track archival magnetic tapes containing only uppercase characters with no diacritics. In the GNIS production flow, DMA will geographically sort this tape data into 15 minute squares and transfer the information to a nine-track tape. The NTF Tape Loader program will read the nine-track tape into the Plessey system, convert uppercase characters to upper- and lowercase characters, and develop the names record format. Records may be accessed later through the NTF Editor for editorial corrections and geographic coordinate digitization.

The NTF Editor allows the toponymist to manipulate the names records built by the NTF Loader. Five main modules are accessed by the NTF Editor: Select, Digitize, Edit, Delete, and Add. The Select module accesses records sequentially or directly by record number. The Digitize module registers source maps, captures raw table coordinates, and converts the raw data to geographic coordinates. The geographics are then used to generate Universal Transverse Mercator (UTM) coordinates and Joint Operations Graphic (JOG) map series numbers. Upon completion of the digitizing, a proof plot may be generated. The Edit module takes the ECD terminal OFFLINE. Using the word processing features of the terminal, a record can be edited. The unique characteristics of Translex allow the insertion and display of diacritical marks. When editing is complete, the user initiates a command which performs an integrity check on the record, places the ECD ONLINE, and sends the record back to the PDP 11/23. The Delete module allows the user to delete any selected record. The Add module accommodates the addition of new records for a geographic area. The user may add as many records as were specified in the NTF Tape Loader program.

NTF Create is the final program, and it produces a gazetteer tape or an intermediate tape for alphabetic sorting by the Multiset III. The sorted tape may be recycled through the NTF Editor for further modification, while the gazetteer tape may be used for the addition of typesetting information prior to printing.

GNIS and the Future

The prototype GNIS has deficiencies as a production system, but will be improved and serve as the foundation for a Foreign Place Names Information System. The two most obvious drawbacks of the prototype system are a lack of mass storage and an inability to perform local sorting. With the addition of a 300 MB disk, the system should accommodate all files except those for the largest countries. A larger capacity will also permit comprehensive sorting. Another desirable option would be the addition of a direct communications link with the Multiset III. This would eliminate the need to physically transfer data to the typesetter on tape. It is anticipated that these improvements will be made in a system upgrade.

DMA's long-term goal is the development of an all digital Foreign Place Names Information System. From the GNIS Names Type File, a data base will be developed to incorporate the information currently contained in the Foreign Place Names File, and additional information required by names applications specialists and map compilers for map production. In addition to integrating and consolidating names production within DMA, the system will be directly accessible to qualified users in the public and private sectors.

EFFECT OF RESOLUTION ON INFORMATION CONTENT OF TEMPORAL PROFILES OF VEGETATION

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ABSTRACT

Landsat has provided the capability to track vegetation development in acre-sized pixels. As this resolution is sub-field sized for most crops of interest, pure pixels of a single crop are not uncommon. Frequency of Landsat acquisition, however, is not adequate to provide a reliable estimate of the crop condition without supplemental information. The NOAA-6 and -7 AVHRR system can provide daily tracking of vegetation over limited areas, at a resolution of one kilometer, and worldwide, at a sampled pixel resolution of four kilometers. These data are further smoothed by some users to fit a 25-kilometer grid data base. Pure pixels do not exist at this coarser scale and questions arise as to the vegetation information retrievable.

Using field inventory data taken in support of the LACIE and AgRISTARS programs, simulation of these coarser resolution data have been made for twelve widely scattered test sites in the central United States. Indications to date are that significant information concerning vegetation condition remain at even the coarsest resolution considered, but, it is highly sensitive to location if used alone. Further, the vegetation information recoverable from combining Landsat and NOAA satellite data is significantly increased over that of using the two sources separately.

INTRODUCTION

In many applications of remotely acquired spectral data "high" spatial resolution is considered desirable. This has been particularly true in the use of satellite acquired spectral data to classify or inventory crop type where one of the limiting factors on accuracy in classification has been occurrence of pixels in which more than one field, or class of targets, is in the instantaneous field of view (mixed pixels). Higher resolution would reduce the percent of occurrence of these mixed pixels, hence, improve upon the accuracy of classification. Reason dictates there must exist some "most useful" resolution for a specific problem. If in the case of a nation-wide inventory of crop type, resolution were increased to the point that the components of the field (rows of plants or leaves) were discernible, horrendous data throughput problems would be experienced, with very little, if any, benefits to compensate for the added effort. Further increase in resolution to the point of microscoptic observation would make the problem insolvable. The point to be made is that, depending on the problem to be addressed, there is a limit to the spatial resolution desired. Just as there is a most desirable spatial resolution, there is a most desirable temporal resolution or frequency of view. Again, the value of this is highly problem dependent.

In practice, in the design of observational systems, a trade off occurs between spatial and temporal resolution which occurs as a result of limitations on sensor response time, data throughput constraints, power, money, etc. As an example, Landsat MSS provides one acre resolution at a frequency of once every 18 days. Had a 1/4 acre resolution been specified as a requirement, and the data rate held constantly, the frequency would be once every 36 days. Determining the optimum system characteristics for a multiple user system is not a simple or an appreciated undertaking, for often as one user is helped, another is hurt.

Within the AgRISTARS Early Warning Crop Condition Assessment project, the requirement of a technology to identify crop stress, degree of stress and the bounds of stressed areas, over broad areas, is well recognized. To meet this requirement frequent (of the order of 5 days or a week) updates in information are needed during critical parts of the growing season. The need for high resolution, however, is questionable. The existing user for the output is only able to track crop condition in time on a 25 mi. square grid (400,000 landsat pixels).

The NOAA AVHRR system appears to provide many of the characteristics required of the data. Vegetative Indices can be constructed from Channel 1 and 2 of this system. Dependent on the scan angle constraints imposed by the analyst, acquisition can be obtained more than once daily at full $\pm 56^{\circ}$ scan angle, every other day at $\pm 28^{\circ}$ scan angle; every fifth day at $\pm 14^{\circ}$ scan angle. This compares to each 18 day for the $\pm 5^{\circ}$ scan angle of Landsat. The resolution of the AVHRR system is at best $(1km)^2$ at nadir (available on a limited basis) and $(4km)^2$ (sampled) at nadir on a world wide basis. This resolution certainly will provide few pure crop pixels but may be adequate to provide a description of general pattern of crop stress. The objective of the work described here is to determine the most effective scale of input to the analysis of broad scale crop condition and to determine what information is lost in going from Landsat sized pixels to the 25 km mile grid. This work is still in progress but some results to date are informative.

APPROACH

During the course of the LACIE (Large Area Crop Inventory Experiment) scattered sites (5x6 n. mi. in size) were selected as Intensive Test Sites. For these sites inventory of scene content were performed and every effort was made to acquire all possible Landsat data. These sites were scattered over the Great Plains and Midwest from Canada to the Gulf, hence a wide variety of crops, cropping practices, and soils were included (Fig. 1). Each Landsat pixel was classified using the ground truth inventory. Registration between acquisitions were performed. In some cases multiple years of data were acquired. With the extensive ground truth available and much of the preprocessing of satellite data already performed, this was deemed an ideal data set to use in considering the effect of scale on information content.

Software was developed (METSIM, Austin 1982) to go from the data to simulation of the scale of output of AVHRR Local Area Coverage (LAC) and Global Area Coverage (GAC) which have $(1\ Km)^2$ and $(4\ Km)^2$ resolution respectively. The relative scale of these Landsat pixels and the 5x6 n. mi. sample segments are shown in Figure 2. It should be noted that while the simulated GAC data is an average over all Landsat pixels contained, the operational GAC data is a sample from the full resolution AVHRR data. GAC sampling provides a data value which is the average of four contiguous pixels. On every third scan, four pixels are averaged for a data value, the fifth pixel is skipped, and then four more pixels are averaged. This is repeated for the scan. Consequently, on a sampled scan line, 409 data points are recorded for the 2048 pixels. The sampling technique for six lines is:

```
 O O O O | O | O O O O | O | O O . . .
(X X X X)| X |(X X X X)| X | X X . . .
 O O O O | O | O O O O | O | O O . . .
 O O O O | O | O O O O | O | O O . . .
(X X X X)| X |(X X X X)| X | X X . . .
 O O O O | O | O O O O | O | O O . . .
```

with the mean value of the four sampled pixels recorded. The four encircled full-resolution points (X) represent one GAC value.

For our purposes, LAC was simulated by a cell: 221 Landsat pixels grouped 13 lines by 17 columns on the LACIE segment. GAC was simulated by a block: a grouping of 16 cells, 4 cells by 4 cells, or 68 Landsat columns by 52 Landsat lines. The software program provided flexibility in positioning the blocks. There is no suitable procedure for simulating the high frequency AVHRR data using the low frequency Landsat data, although Badhwar (1982) has devised a curve fitting technique that can support some comparisons.

Subtle change in temporal profile can be important indicators of anomalies in crop condition. This can only be tracked with the higher frequency data. The temporal plots shown here are the best that could be acquired using both Landsat 2 and 3. The vertical coordinate is proportioned to the ratio of Landsat MSS Channel 4 to Channel 2. The horizontal coordinate is day of the year.

RESULTS OF ANALYSIS

Only a small fraction of the results acquired to date can be shown here. More detailed description is in preparation as an AgRISTARS Technical Report.

In this discussion the term "cell" refers to a simulated AVHRR LAC pixel generated from approximately 250 Landsat pixels (See figure 2). A "block" is 16 cells. Crop profiles are for individual fields within the Intensive Test sties. The amount and/or vigor of vegetation is assumed to increase with the ratio of MSS Channel 4 to MSS Channel 2.

In Figure 3 the temporal profiles for major components of the Hines County Mississippi Site are shown. For each of the crop categories shown, a general pattern is discernable, although there is considerable difference between the profile of different fields of the same crop. The largest difference in patterns occurs in corn. This may be due to the different ways corn can be used, abandoment, or mislabeling of the inventory. In Figure 4, the temporal profile for major components of the Traverse County, Minnesota test sites are shown. Again, some definite patterns exist for each crop. The differences between fields is somewhat less than that shown for the Mississippi crops due in part to the dictates of a shorter growing season. Pasture again shows a great deal of difference in fields due to different management practices.

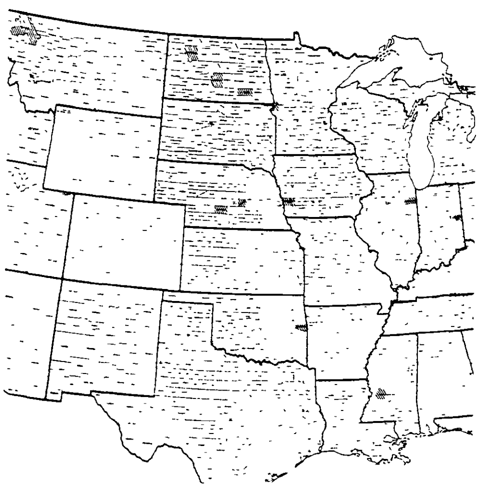


Fig 1. Geographical Distribution of Sites

In Figure 6 a comparison is made between the 4 blocks contained in the test site segment. The composition of each block is given in the insert. While some modest differences occur in composition the difference between block profiles is considerably less than that between cell profiles. The significant point to be made in Figures 5 and 6 is that in this case:

1) Restricting consideration to vegetation only can make significant differences at the cell level but at the Block level its impact is small.

2) Differences between cells are considerably greater than differences between blocks.

The reason for this is built into the practical scale of agriculture as performed in this region. Each farm has its homestead, its woodlot, pond etc; there are roads, cross-roads, communities, schools. Each of these features which has little to do with crop condition can make significant impact on a cell, but for a block these features tend to settle down to a stable percentile. We have found that farther to the west were topographic features are more pronounced and cultural impact less apparent, more difference between blocks sometimes occurs.

The question remains, can the GAC simulated data which contains all the components of a scene show sufficient detail in temporal profile to infer general crop condition? Figure 7 compares profiles of fields of corn and fields of soybeans in 1970 to the fields in 1978 for the Kankakee County, Illinois test site. Both crops show flatter, but prolonged profiles in 1979 than in 1978. Figure 8 compares the profiles for two of the cells in two of these blocks of this site between years. Again, the characteristic difference between years is a flatter but prolonged profile in 1979. It appears in this case (as in other cases studied) the simulated GAC profile does provide sufficient detail to track general crop condition.

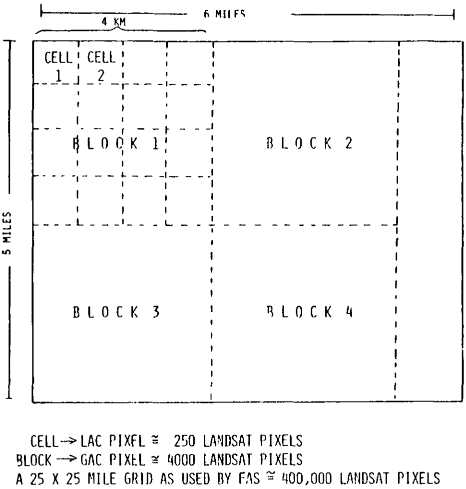
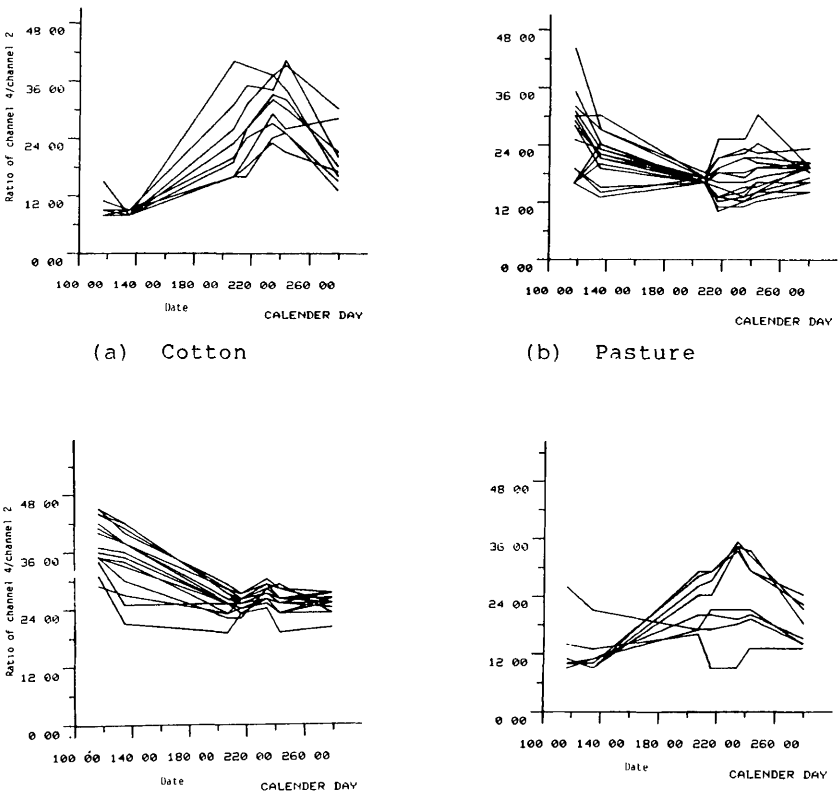


Figure 2. Simulation of Metsat Information Content Using LANDSAT and LACIE Ground Truth



(a) Cotton (b) Pasture

(c) Trees (d) Corn

Fig. 3. Hines County, Mississippi Site Temporal Profiles for Major Categories

In both Figures 3 and 4 some rather abrupt changes in profile slope occur due to the small number of Landsat data points upon which to base the curve. The important message in these figures is: For a given location-year, general patterns in temporal vegetation profiles appear for a specific crop, however significant differences occur between fields for a given crop.

In Figure 5 (again Traverse County, Minnesota), the profiles are shown not by crop, but by cells in one block of the test site. Figure 5a shows a definite general pattern but with considerable difference between cells. In Figure 5b the envelope of standard deviation for those data are shown as solid lines with abrupt changes in slope. The block mean is shown as dots, and a smoothed depiction of block profile as determined using the Badhwar Technique is shown. All pixels in the block were used in arriving at Figures 5a&b. In Figure 5c only those pixels in each cell that were classified as vegetation were used. The overall pattern is very similar although some cells have changed considerably. The statistics and simulated curves for the two are almost identical.

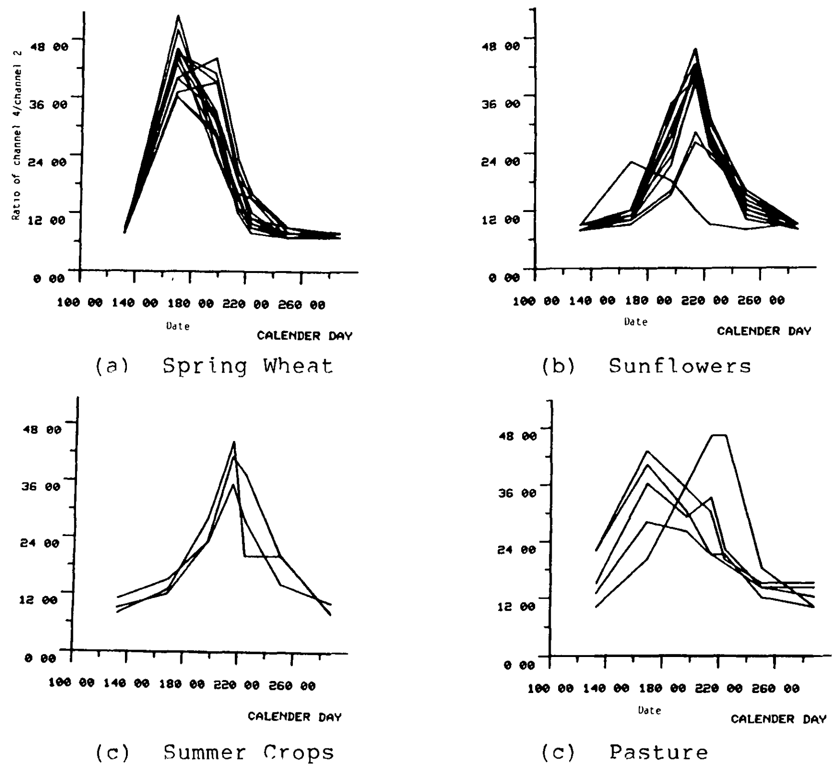
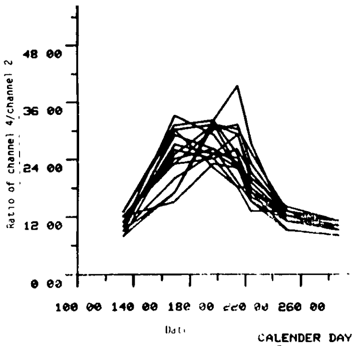
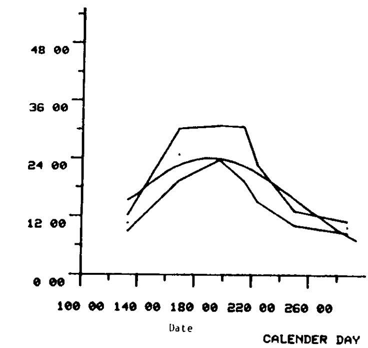


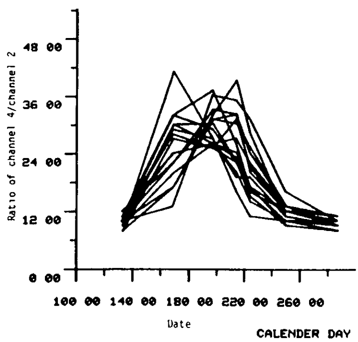
Fig. 4. Traverse County, Minnesota Site
Temporal Profiles for Major Categories



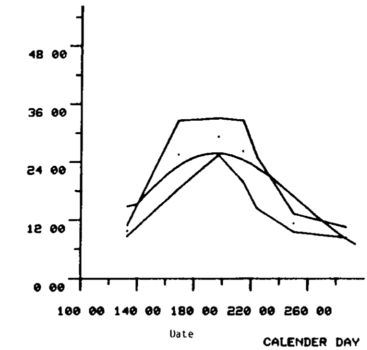
(a) Block 1 Cell Profiles



(b) Block 1 Statistics or Curve Fit



(c) Block 2 Cell Profiles



(d) Block 2 Statistics and Curve Fit

Fig. 5. All Pixel Input by Cell, Profile Statistics and Curve Fit Traverse County, Minnesota

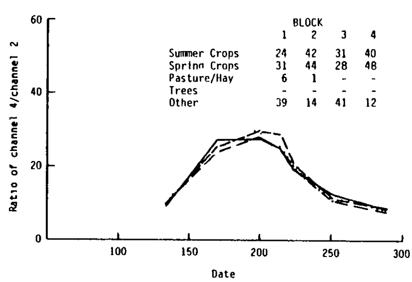
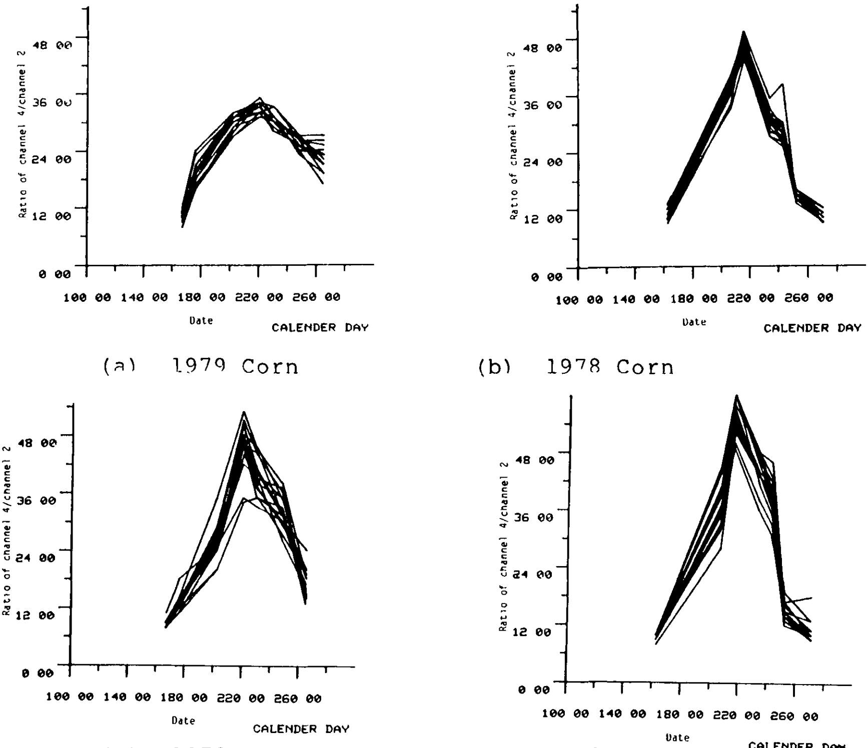


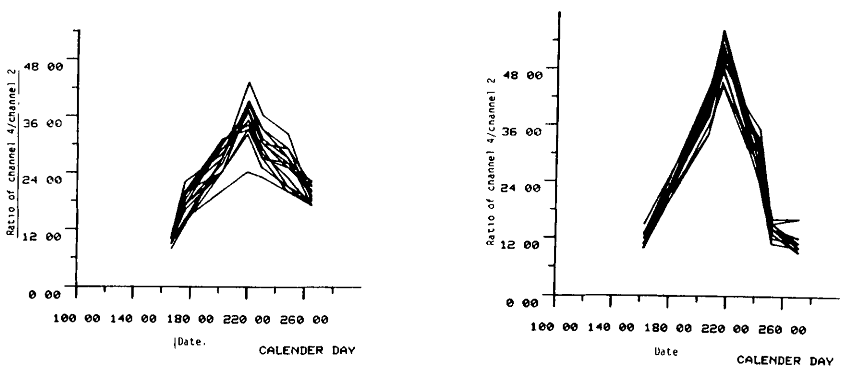
Figure 6. Comparison of Composition and Profile for the 4-Block in Traverse County, Minnesota Site



(a) 1979 Corn (b) 1978 Corn

(c) 1979 Soybean (d) 1978 Soybean

Fig. 7. Comparison of 1979 and 1978 Crop Profiles Kankaku County, Illinois Site



(a) 1979 (b) 1978

Fig. 8. Comparison of 1979 and 1978 Profiles for Block 1, Kankaku County, Illinois

CONCLUSION

With the study still in progress it is not possible to yet specify the most effective spectral scale for our purpose. It appears, based on the results shown here and other cases, considered in the parent study that little information is lost concerning the general vegetative condition for large areas if the pixel size is increased to the AVHRR/GAC scale. The cost in information content as larger pixels (up to 25 n. mi. on a side) are considered is yet to be determined. It also appears that because the topographic and demographic features and cropping practices vary from location to location the ability for the GAC scale to track general crop condition may be dependent on some means of identifying the percent of scene fitted by each component. This may be estimated by past record but in areas of dynamic agriculture change it may require once a year inventory taken by much higher resolution sensors.

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Austin, W. W., and W. E. Ryland, 1982, Simulation of Meteorological Satellite (Metsat) Data using LANDSAT Data., AgRISTARS EW/CCA Technical Report, in printing.

Badhwar, G. D., J. G. Carnes and W. W. Austin, 1982, Use of Landsat-Derived Temporal Profiles for Corn-Soybean Feature Extraction and Classification, Remote Sensing of Environment, 12-57-79.

AN AUTOMATED DATA SYSTEM FOR STRATEGIC ASSESSMENT OF LIVING MARINE RESOURCES IN THE GULF OF MEXICO

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ABSTRACT

This paper briefly describes and illustrates the features of a computer-based data system designed to provide easy access, manipulation, retrieval, and display of information on the temporal and spatial distribution of living marine resources in the Gulf of Mexico. This data system is one component of a larger system being developed by the Office of Ocean Resources Coordination and Assessment (ORCA) of the National Oceanic and Atmospheric Administration (NOAA) to analyze the distribution of living marine resources in all U.S. coastal and ocean regions, excluding the Great Lakes.

INTRODUCTION

Development of the Automated Data System for Strategic Assessment of Living Marine Resources in the Gulf of Mexico is an integral part of ORCA's strategic assessment project for that region (ORCA, 1981). The overall Gulf of Mexico project, second of a series of five strategic assessments that will cover the entire "coastal zone" of the U.S.A., extending seaward to the 200-mile limit of the fishery conservation zone, was initiated in 1980. These assessments are described as "strategic" because they are carried out from a long-term and large-scale planning perspective intended to complement, not replace, the necessary detailed, site-specific or "tactical" analyses of specific ocean use proposals (Ehler and Basta, 1982).

The Gulf of Mexico strategic assessment project focuses on the entire Gulf, including the coastal and ocean waters of both the U.S.A. and Mexico. The project is developing data on the distribution of various characteristics of the region, including: 1) physical characteristics; 2) plants; 3) marine animals; 4) economic activities and their pollutant discharges; and 5) management jurisdictions. These data, in conjunction with analyses performed using pollutant transport models (Duke, et al., 1980, and ORCA, 1982), will be used as a basis for identifying and understanding better some of the relationships between and among economic activities, their pollutant discharges, and living marine resources in the Gulf of Mexico.

The system has two primary objectives: 1) to support the analyses of living marine resources conducted as part of ORCA's national Strategic Assessment Program; and 2) to provide a rapid-turnaround analytical tool to assist NOAA resource management and project review activities, such as those undertaken through its Office of Habitat Protection, Office of Marine Pollution Assessment, and ORCA. Upon completion of the first phase of the Strategic Assessment Program, the data system will combine in a single consistent data set information on the spatial and temporal distribution of important living marine species for all U.S. coastal and ocean waters.

THE SYSTEM

The Gulf of Mexico data system is comprised of life history and economic activity data for 73 species of marine fishes, invertebrates, mammals and reptiles (see Table 1). These data have been collected primarily from the literature by biologists of NOAA's National Marine Fisheries Service (NMFS).* Based on these data, NMFS biologists have prepared maps to illustrate the spatial and temporal characteristics of the life history, as well as important commercial and recreational fishing grounds, of each species.

Species	Scientific Name
INVERTEBRATES+	
Clam, Sunray Venus	*Marcocallista nimbosa*
Conch, Queen	*Strombus gigas*
$Crab, Blue	*Callinectes sapidus*
$Crab, Stone	*Menippe mercenaria*
$Lobster, Spiny	*Panulirus argus*
Octopus, Common	*Octopus vulgaris*
Octopus, Mexican Four-Eyed	*Octopus maya*
$Oyster, American	*Crassostrea virginica*
Scallop, Calico	*Argopecten gibbus*
Seabob	*Xiphopenaeus kroyeri*
$Shrimp, Brown	*Penaeus aztecus*
$Shrimp, Pink	*Penaeus duorarum*
Shrimp, Rock	*Sicyonia brevirostris*
Shrimp, Royal Red	*Pleoticus robustus*
$Shrimp, White	*Penaeus setiferus*
Squid, Long-finned	*Loligo pealei*
FISHES	
Amberjack, Greater	*Seriola dumerili*
Bluefish	*Pomatomus saltatrix*
Bonefish	*Albula vulpes*
Butterfish, Gulf	*Peprilus burti*
Cobia	*Rachycentron canadum*
Croaker, Atlantic	*Micropogonias undulatus*
Dolphin	*Coryphaena hippurus*
Drum, Black	*Pogonias cromis*
Drum, Red	*Sciaenops ocellatus*
Flounder, Dusky	*Syacium papillosum*
Flounder, Gulf	*Paralichthys albigutta*
Flounder, Southern	*Paralichthys lethostigma*
Grouper, Black	*Mycteroperca bonaci*
Grouper, Red	*Epinephelus morio*
Grunt, Tomtate	*Haemulon aurolineatum*
Herring, Atlantic Thread	*Opisthonema oglinum*
Herring, Round	*Etrumeus teres*
Jack, Crevalle	*Caranx hippos*
Mackerel, King	*Scomberomorus cavalla*
Mackerel, Spanish	*Scomberomorus maculatus*
Marlin, Blue	*Makaira nigricans*
Marlin, White	*Tetrapturus albidus*
Menhaden, Gulf	*Brevoortia patronus*
Mullet, Striped	*Mugil cephalus*
Pompano, Florida	*Trachinotus carolinus*
Porgy, Longspine	*Stenotomus caprinus*
Runner, Blue	*Caranx crysos*
FISHES (cont.)	
Sailfish	*Istiophorus platypterus*
Sardine, Spanish	*Sardinella anchovia*
Seatrout, Sand	*Cynoscion arenarius*
Seatrout, Spotted	*Cynoscion nebulosus*
Shark, Shortfin Mako	*Isurus oxyrinchus*
Shark, Scalloped Hammerhead	*Sphyrna lewini*
Snapper, Gray (Mangrove)	*Lutjanus griseus*
Snapper, Gulf Red	*Lutjanus campechanus*
Snapper, Lane	*Lutjanus synagris*
Snapper, Mutton	*Lutjanus analis*
Snapper, Vermilion	*Lutjanus vivanus*
Snapper, Yellowtail	*Ocyurus chrysurus*
Snook	*Centropomus undecimalis*
Spot	*Leiostomus xanthurus*
Swordfish	*Xiphias gladius*
Tarpon	*Megalops atlanticus*
Tilefish	*Lopholatilus chaemaeleonticeps*
Tuna, Blackfin	*Thunnus atlanticus*
Tuna, Bluefin	*Thunnus thynnus*
Tuna, Little Tunny	*Euthynnus alletteratus*
Tuna, Yellowfin	*Thunnus albacares*
REPTILES	
Alligator, American	*Alligator mississippiensis*
Crocodile, American	*Crocodylus acutus*
Crocodile, Morelet's	*Crocodylus moreleti*
Sea Turtle, Loggerhead	*Caretta caretta*
Sea Turtle, Kemp's Ridley	*Lepidochelys kempi*
MAMMALS	
Dolphin, Bottlenose	*Tursiops truncatus*
Dolphin, Spotted	*Stenella plagiodon*
Manatee, West Indian	*Trichechus manatus*
Whale, Fin	*Balaenoptera physalus*
Whale, Short-finned Pilot	*Globicephala macrorhynchus*

+ Preliminary tests run for invertebrates only.
$ Indicates major commercial invertebrate in U.S.A.

Table 1. Species included in Gulf of Mexico data system

At least four types of areas are identified on each species map:

1. Adult Area: An area in which sexually mature individuals of a species occur;

2. Reproductive Area: An area in which spawning (for fishes and invertebrates) or calving or

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* Life history data on Gulf of Mexico species were organized by the Panama City Laboratory, Southeast Fisheries Center, National Marine Fisheries Service, NOAA, located in Panama City, Florida.

pupping (for marine mammals) or nesting (for reptiles and birds) occurs;

3. Nursery Area: An area in which larvae, juveniles, or young stages of a species occur or concentrate for feeding or refuge; and

4. Exploitation Area: An area in which living marine resources are harvested for commercial, recreational, or subsistence purposes.

Draft maps were drawn at a scale of 1:2,000,000, or 1 inch = approximately 32 miles. This large scale was necessary to illustrate on a single map the spatial extent of marine species in the Gulf since many range throughout the entire Gulf. These maps will be reduced to a scale of 1:4,000,000 and published in a Gulf of Mexico Data Atlas (ORCA, 1981) being developed as part of the regional project.

The system converts data on the temporal and spatial distribution of the life history, as well as the commercial and recreational fishing grounds, of each species into a computerized 10-minute by 10-minute square (approximately 10-mile by 10-mile) grid system covering the entire Gulf of Mexico. The process of translating mapped data into digital data has been designed to provide, as closely as possible, a literal representation of each species map. Once coded, the data are stored in the automated data system and a map of each species can then be produced by the computer. Figure 1 illustrates a computer-generated map of brown shrimp adult areas throughout the year.

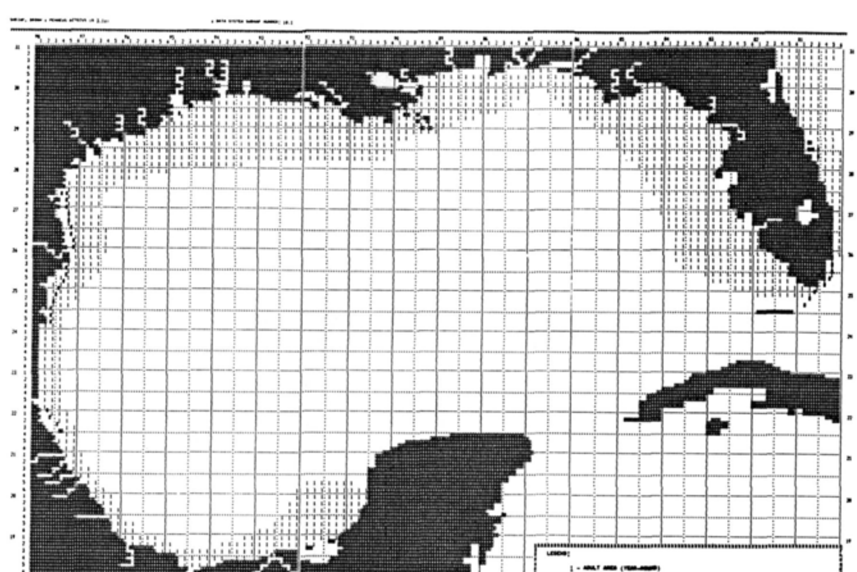

Figure 1. Computer-generated map of brown shrimp adult areas, year-round

A user can perform at least two relatively simple operations on the stored life history data: 1) composite mapping of the presence or absence of any combination of species, their life histories, or seasonality across the entire 10-minute square grid system or any portion of it; and 2) an examination and comparison of the presence or absence of species and life history for any season within any individual grid cell or set of cells. The composite mapping feature produces a schematic map showing numbers of types of species in each 10-minute cell, a simple measure of species diversity. Results can be displayed either as the total number of types of species or as shaded intervals. Since most of the detailed life history and seasonal information displayed on the hand-drawn maps is preserved in the system, a wide variety of composite maps can be developed. For example, maps can easily be made of the winter or summer distributions of the spawning areas of the top twenty commercial fish species, or for selected biological groupings of species (e.g., groups aggregated by tolerance to seasonal temperature changes), or for areas of adult concentrations of specified species groups during a particular season of the year.

The second operation enables the user to assess specific attributes of marine species within selected areas described by any combination of 10-minute square grid cells. For example, life history stages or fishing grounds of species found within 30 miles of proposed or active ocean dump sites or within estuaries in the Gulf of Mexico can be easily listed. For any specified area the system can provide a listing of the life history stages of each species found within the area, the seasonality of the individual life history stages, and the total number of 10-minute cells within the area occupied by each life history stage of each species for each season. In a manner similar to the composite mapping feature, this listing can incorporate all or any combination of marine species, life history stage, and season. The system can also compare areas. For example, the system could be used to compare the spatial and temporal distributions of living marine resoures in the U.S.A. fishery conservation zone and Mexican "exclusive economic zone" of the Gulf of Mexico, or the relative biological importance of existing or proposed offshore oil and gas exploration and production areas.

In conjunction with these basic operations, a number of criteria can be used to emphasize the relative importance of a particular species, group of species, life history stage, or other attribute. For example, commercial species can be weighted by their relative economic value, or by the spatial extent of areas in which a specified life history stage of a species takes place. The weighting scheme and individual weights that could be used depend on the specific problem context in which the data system is applied. Care is required in choosing a meaningful weighting scheme, regardless of the problem context.

TEST RUNS FOR INVERTEBRATES

Preliminary test runs of the data were made to illustrate the capabilitiy of the system. Invertebrates were arbitrarily chosen for this illustration for two reasons: 1) they are by far the most economically valuable group of marine species in the Gulf of Mexico*; and 2) only 16 invertebrates are included in the data system (compared to 48 fishes), making them much easier initilly to code, edit, and enter. Several combinations of invertebrate species, life history stage, exploitation activity, and season were selected. For each combination the system generated a computer map which aggregated data for each species according to the attributes specified. Several of these combinations are illustrated below.

Two types of criteria (weights) were applied to the species data used in these test runs: "areal extent" and "economic value." In the context of the weighting scheme used in these test runs, the term "areal extent" represents the spatial extent of an area or areas occuppied by a species during a particular life history stage and season. For example, if the spawning areas of a species were uniformly distributed throughout 250 cells (each 10 minutes by 10 minutes) within the Gulf during the spring, then the "areal extent" value for each cell would be 1/250; if a species was uniformly distributed throughout 10 cells, then each cell would have a value of 1/10.** Given a specified combination of species, life history stage, and season, the system sums the areal extent values in all cells and produces a shaded computer map which places the sum of values for each cell in intervals to highlight differences among areas. Those areas in the highest intervals, i.e., the darkest areas shown on each map, have the highest relative areal extent value and are candiates for additional analysis. Each of these areas should be reviewed in detail on a species-by-species basis before conclusions are drawn. An area can have a high areal extent value for several reasons. It could contain a few species with very high values, many species with moderate values, or combinations between.

The economic value weights used are based on the commercial value of catch in 1980 (NMFS, 1982). These weights have only been applied to the seven major commercial species: blue crab (Callinectes sapidus); stone crab (Menippe mercenaria); spiny lobster (Panulirus argus); American oyster (Crassostrea virginica); brown shrimp (Penaeus aztecus); pink shrimp (Penaeus duorarum); and white shrimp (Penaeus setiferus). A weight for economic value was computed for each species based on its percent of the total dollar value of invertebrate catch. These weights were then multiplied by the areal extent values for each species. Computer-generated maps where then produced as described above. Areas identified in the highest interval that are weighted by both areal extent and economic value provide an indication of areas

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* Seven of these 16 invertebrates account for approximately 75% of the total value of U.S. commerical fish catch in the Gulf of Mexico (NMFS, 1982).

** Computing values of "areal extent" in this manner assumes that species are uniformly distributed throughout a specified area. While this is admittedly an unrealistic assumption, it is a necessary one given limitations of existing knowledge and data about the distribution in space and time of most species' life histories. However, the ORCA data system is capable of differentiating values among individual cells, given the necessary data. For example, an experiment is currently underway to use the bottom trawl survey data of the Northeast Fisheries Center of the National Marine Fisheries Serive, NOAA, for exactly this purpose.

that may not only be biologically important, but could also produce the greatest economic loss due to adverse impacts.

Initial results of these first runs simply illustrate some of the features of the system. For example, when data are weighted only by areal extent (Figure 2), coastal waters off of southwestern Florida are in the highest interval. In fact, the areal extent values of cells in this area are by far the highest in the Gulf for nursery areas. Since values are also very high when only major commercial species are considered (Figure 3), this group probably dominates the areal extent value of the area. However, when the data are also weighted by economic value (Figure 4), the combined values in cells in this area decrease dramatically (although the area is still in the highest interval). This is primarily because of the relatively low economic value of blue crab and spiny lobster which dominate areal extent values in the area.

Another example can be illustrated by Figures 5 and 6. When summer spawning areas for major commercial species are weighted only by areal extent (Figure 5), no areas stand out as having very high areal extent values relative to other areas, although a few are slightly higher than others. This is because spawning areas for most of the major commercial species are generally in large offshore areas. Therefore, each species has a relatively low areal extent value. However, when the data are also weighted by economic value (Figure 6), one offshore area in the northern Gulf has very high combined values compared to others. The primary reason for this is the presence of both brown and white shrimp spawning in this area during the summer and the very high economic value of these species.

Although admittedly simplistic, these two examples provide an indication of some of the capabilities of the system. They show the potential of the system for relatively easy manipulation of information on life history stages, seasons, and commercial and recreational fishing grounds for a large number of important marine species within a consistant analytic framework. The maps shown above represent only one type of display and data aggregation that the system can produce. Various other displays, data aggregations, and weighting schemes will be used to analyze a number of problems related to conflicts between economic activities and living marine resources in the Gulf of Mexico. This capability is not a substitute for the judgments and interpretations of expert marine biologists. On the contrary, it is complementary and can enhance and expand the range of issues on which expert judgement can be made.

Development of this data system is a continuing process and is only one of several analytic methods and tools being developed as part of ORCA's Strategic Assessment Program. As additional and improved information becomes available, the data system will be upgraded. For example, the same formats will be used to display the spatial and temporal distribution of other physical characteristics of the region such as bathymetry, surface and bottom temperature, salinity, and sediment type, or economic data such as weight of fish catch. Use of this system in conjunction with other components of the program will provide a basis for understanding better the relationships between living marine resources and human activities in the Gulf of Mexico.

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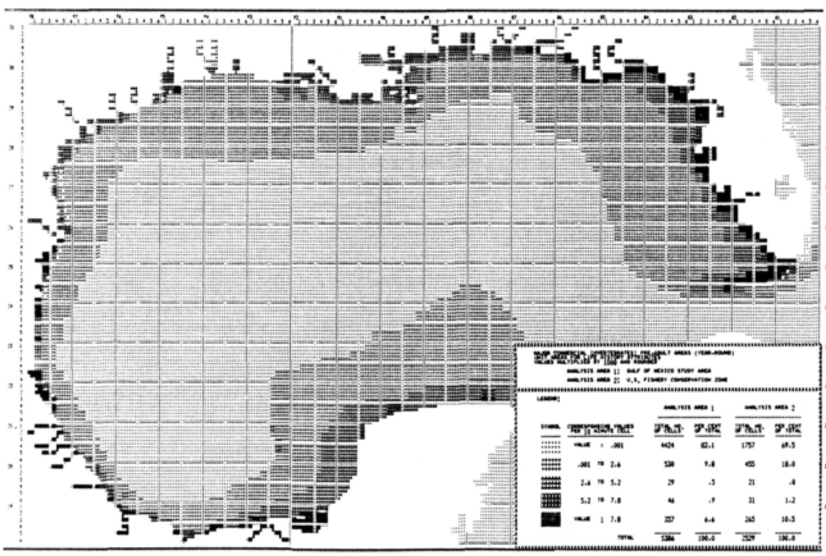

Figure 2. Computer-generated map of invertebrate nursery areas, year-round (weighted by areal extent)

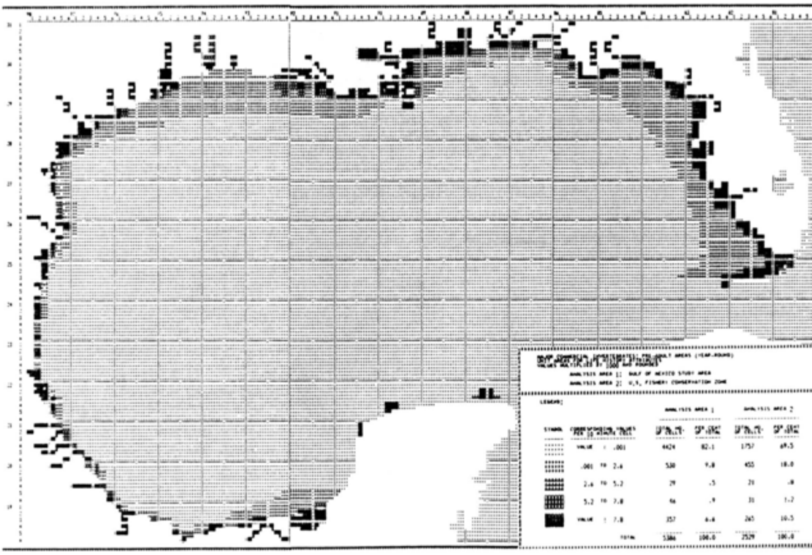

Figure 3. Computer-generated map of major commercial invertebrate nursery areas, year-round (weighted by areal extent)

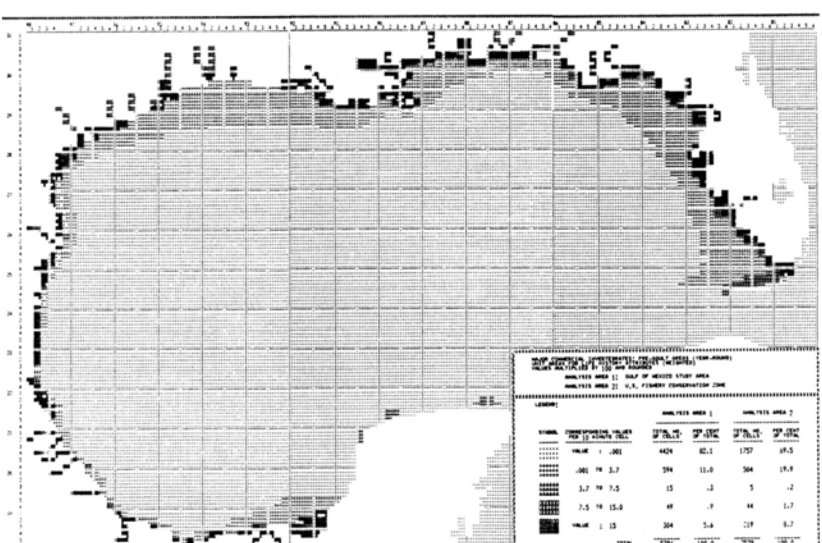

Figure 4. Computer-generated map of major commercial invertebrate nursery areas, year-round (weighted by areal extent and economic value)

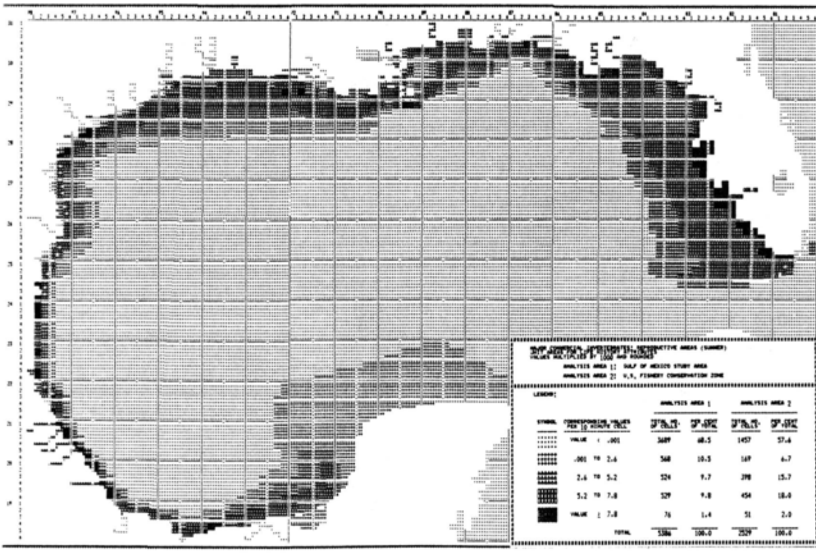

Figure 5. Computer-generated map of major commercial invertebrate spawning areas, summer (weighted by areal extent)

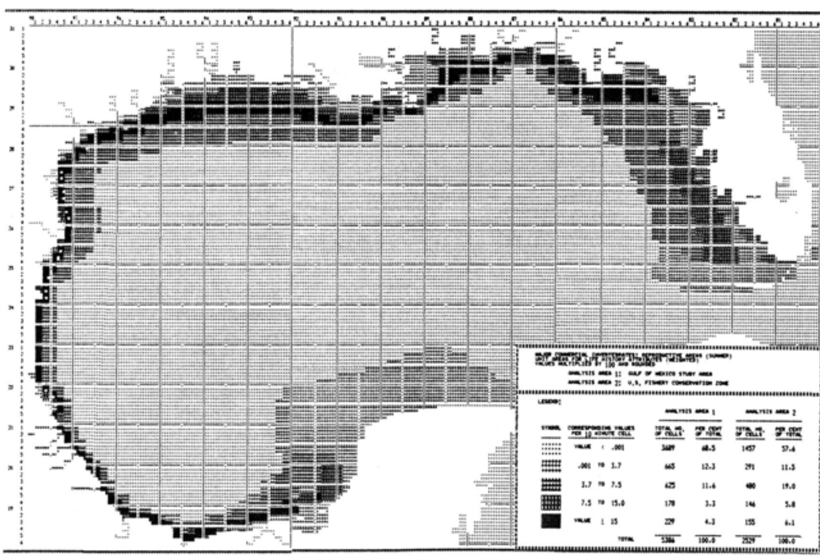

Figure 6. Computer-generated map of major commercial invertebrate spawning areas, summer (weighted by areal extent and economic value)

COMPUTER ASSISTED MAPPING AS PART OF A STUDY ON ACID RAIN

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ABSTRACT

Recently the University of Minnesota, Duluth and the Environmental Protection Agency have begun a study titled "Inventory and Documentation of the Susceptibility of Aquatic Resources to Damage by Airborne Pollutants." The airborne pollutant of most concern is acid precipitation and the object of the inventory and documentation is to develop a modeling methodolgy to discern the susceptibility of aquatic resources in various environments to damage from airborne pollutants. The study site is the Upper Midwest Lake States, with data collection focused on Northeastern Minnesota, Northern Wisconsin and Upper Michigan. The data collected in the inventory are being placed in a large computerized data base. Part of the analysis and documentation calls for the use of computer assisted mapping.

This paper is a progress report on how computer assisted mapping and data base management is being used for this project. There will be a discussion of how several off-the-shelf computer mapping programs (e.g. GIMMS, EPPL, and SURFACE II) are being utilized. The paper documents an attempt to use the World Data Bank II as a GBF for this project. Specialized software developed for the project is also described.

INTRODUCTION

Various units of the College of Letters and Science at the University of Minnesota, Duluth (UMD) are cooperating in a study titled "Inventory and Documentation of the Susceptibility of Aquatic Resources to Damage by Airborne Pollutants." This study is part of a larger "Airborne Pollutant Impacts Research/Assessment Program" managed by the Enironmental Protection Agency's Environmental Research Laboratory-Duluth (ERL-D)*. The UMD study involves many different

* Although the research described in this paper has been funded wholly or in part by the United States Environmental Protection Agency through contract or grant CR809332-01-00 to The University of Minnesota, it has not been subjected to the Agency's required peer and policy review and therefore does not necessarily reflect the view of the Agency and no official endorsement should be inferred.

components, but a common theme is the collection and analysis of data coverng a broad geographical area. Although the collection of data is not a topic for this paper, the computerized data handling, analysis, and display of it, within it's geographical context, is our concern.

The UMD study encompasses several levels of geography. The highest (or macro) level is the land area around the three upper Great Lakes (Huron, Michigan, and Superior). This includes sections of the States of Michigan, Wisconsin, and Minnesota, and part of the Canadian Province of Ontario. The next (or micro) level is the select regions within these four political units. Each of these micro levels in turn is made up of a number of sample sites with each site correspondings to a watershed for a sample lake (see Figure 1).

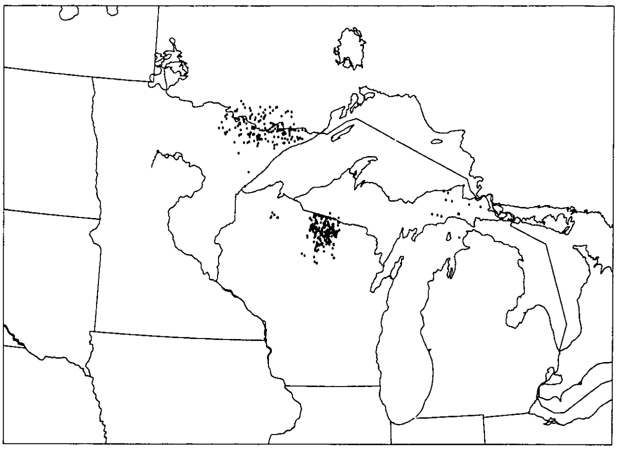

Figure 1: Study Area With Current Sample Sites

Of special concern for this paper are the micro level sample sites within the State of Minnesota. These sites are mostly located in the Superor National Forest. These sites are special because they involve the use of the Minnesota State Geographic Information System.

The project follows a traditional Geochemistry research methodolgy which uses computers for supplemental analysis and display capablities. This research philosophy does not require that a major computerized geographical information system be developed or utilized to coordinate data handling, analysis, and display. The traditional approach simply incorporates into the project those available computer programs which can perform as many of the data handling, analysis, and display tasks as possible. While making no value judgement as to whether this research methodolgy is best, the paper will show the workability of the methodolgy selected for this study, insofar as it concerns computer applications.

The computer programs currently used and those under consideration for future use are reviewed first. The project is currently using, or planning to use, the following existing computer programs or computerized data bases.

1. MLMIS: The Minnesota Land Management Information System, a grid cell based data analysis and display system.

2. World Data Bank II: A geographical data base for North America, which includes definitions of rivers, lakes, and regional boundaries.

3. Surface II: A generalized program for handling spatially distributed data, produces isoline maps and block diagrams.

4. GIMMS: The Geographical Information Mapping and Manipulation System, a high quality polygon based mapping system.

5. Other Software: Examples would include SIR, The Scientific Information Retrieval System, and SPSS, Statistical Package for the Social Sciences.

As part of this review, the use of these programs within the context of the study will be explained. Information on specialized software developed for this project will also be presented.

THE DATA FOR THE STUDY

The data includes a number of variables from a wide range of sources. This data all focuses on the relationship between airborne pollutants and aquatic resources. For example it includes:

1. The chemical make-up of the lake water from the study sites;

2. The chemical make-up of precipitation, both snow and rain;

3. The analysis of the biological aspects of study sites (zooplankton, phytoplankton, fish, etc.);

4. Miscellaneous geographical data, which includes vegetation, surface area of watershed, geology, soils, etc.

The common thread connecting all of this data together is its geographical location. Because of this both the analysis and the display of the data is conducive to computerized geographical mapping and manipulation programs.

THE SOFTWARE AND HARDWARE CONFIGURATION

DATA BASE AND STATISTICAL PROGRAMS

Because of the research methodolgy used, a large number of computer programs are being used. Since the study is ongoing, not all of the decisions about program usage have been made. However, what follows is a review of what is currently being done and what is likely to happen in the future.

THE MLMIS SYSTEM

The MLMIS system is a sophisticated, grid oriented, geographic information system which was developed by units of the University of Minnesota and Minnesota's planning agency (Hsu, 1976). The system dates from the late 1960's but it has undergone substantial improvement over the years. MLMIS allows the user considerable control over the data for manipulation purposes. Some examples of possible data manipulation include:

1. Bigtab: a routine which allows the user to create a new map with a data level for each combination of two variables per grid cell.

2. Flow: will create a new map that is based on logical paths through multiple variables.

3. Score: permits assignment of values relative to the characteristics of each variable and the importance of each variable for the Bigtab process.

4. Edge: analysis where two variable are adjacent to each other.

MLMIS outputs the results of its manipulation in either map or tabular form and uses the Environmental Planning and Programming Language (EPPL). This study utilizes two versions of EPPL. EPPL5, the older of the two, runs on UMD'S computer and will be used for most of the work. A newer version, EPPL6, runs on the state's Department of Energy, Planning & Developments Prime computer system, will be used when its added capacities are necessary. The data file structure is similar for both versions thus facilitating this operating procedure.

In addition to having a very powerful language in EPPL, MLMIS also maintains a number of geographical data bases for the state of Minnesota. This study plans to use these data bases to obtain the geographical data for sample sites within the State of Minnesota. Moreover, much of the data collected for the State is planned to be put into MLMIS formatted data bases which will allow for analysis and display by EPPL (see Figure 2). Some of the data maintained by MLMIS and of interest to this study include:

1. Geology: from geology maps of the state updated with more current field data;

2. Vegetation: such as forest and grassland cover;

3. Soils: from the soil conservation maps of the state;

4. Watersheds: defined for areas of 5 1/2 square miles.

EPPL maps can be output on a wide range of devices, including a Dicomed image recorder, a color CRT, a Benson dot plotter, a Tri-Color printer, and a standard line printer. At UMD only the line printer option is available since the other devices are not currently on site. This precipitated some experimentation with other types of output devices. For instance, experiments have been successfully conducted using an Apple computer-controlled IDS 560G printer and a Zeta pen plotter to print or plot maps produced by EPPL. An experiment is planned using a recently purchased Decwriter 3, with graphics option. Should the Decwriter 3 experiment prove successful, and there is no reason to doubt that it will not, it will probably be used to print EPPL maps for reports etc.

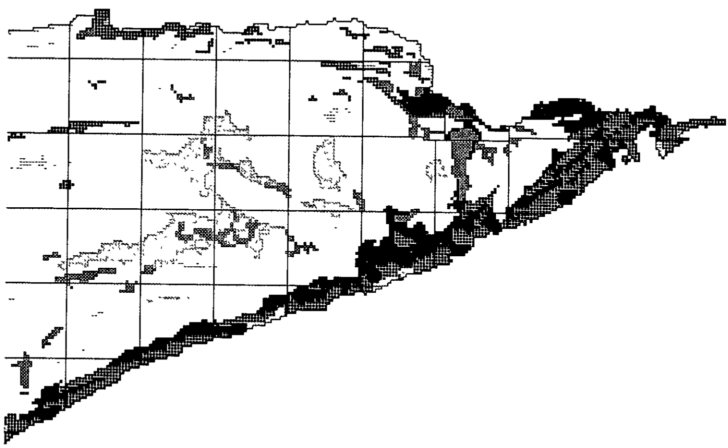

Figure 2: An EPPL Generated Map of Surficial (1-5 feet) Texture for Part of the Minnesota Sample area

The Zeta option, because of the size capabilities and the fact it is possible to create maps in color, can be used to produce poster sized EPPL maps for display. This option is worth going over in more detail because it illusrates how easy it is to interface EPPL to miscellaneous output devices. EPPL allows the user the option of saving a raster formated data file of the map. It is quite easy to take that data and convert it into a formal map. In the case of the Zeta map, all that needs to be done is write a program which plotted a color shaded square at each row and column location. The Z value at that location determines the color, based on a simple classification scheme designated by the user. Since row and column output assumes a regular rectangle, the plotted squares retain the correct geographical shape.

This map data file option also makes it easy to use the output data from EPPL as input to other programs such as SURFACE II.

SURFACE II

Surface II is basically a very sophiscated isoline mapping computer program (Sampson, 1975). The program inputs standard X-Y-Z data, it then grids and displays that data. The user has considerable control over the gridding and display functions, and Surface II can output on either a line printer or a pen plotter (see Figure 3).

It is planned to use the Surface II program to display select data in either isoline maps or block diagrams. Much of the data collected lends itself to isoline mapping. For example, the chemical make-up of precipitation, both snow and rain, could be isoline mapped. This type of mapping would clearly show patterns of concentration for select airborne pollutants.

In addition to mapping raw data, some experiments have been conducted showing the possibility of using Surface II to display output from MLMIS. While the experiments were successful it was not clear that this method of reprocessing MLMIS output by Surface II will be used for the project.

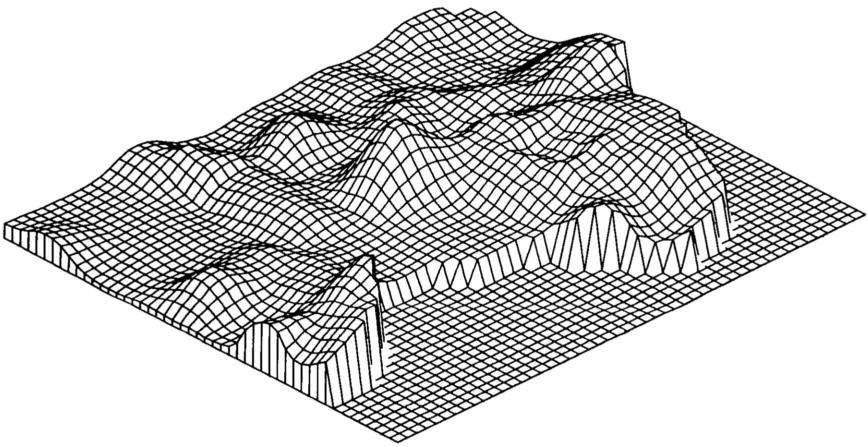

Figure 3: EPPL Data Displayed in a Block Diagram Created by SURFACE II

GIMMS

GIMMS is a general purpose, user oriented, integrated, geographic processing system (Waugh and Taylor, 1976). This means that GIMMS can be used to map any geographical area so long as it is defined (i.e. as a GBF) in a way compatible to the program. GIMMS accepts a wide variety of GBF's including those in the old SYMAP format. The preferred GBF format is labeled line segment strings with which the program can do a considerable amount of polygon checking. GIMMS is extremely user friendly since most of the commands use a very flexible input system called General Parameter Input System (GPIS), which contains over 100 commands and at least another 200 sub-commands (Waugh, 1977). The mapping quality of GIMMS is exceedingly high and the system produces both choropleth and point symbol maps.

GIMMS will be used to display some of the point data (i.e. field collected sample data). The advantage of GIMMS is that it is capable of producing multi-variate symbols, which of course allow for the display of related data from a select sample site. It is planned to convert WDB II data to GIMMS format so it could be used as background for the point symbol maps.

WORLD DATA BANK II

The World Data Bank II (WDB II) is a very large GBF for the whole world which was developed by the United States Central Intelligence Agency. The GBF consists of five reels of magentic tape, one reel of which defines North America. The WDB II format for North America consists of four files, one each for:

1. coastlines, islands, and lakes;

2. rivers;

3. international boundaries;

4. internal boundaries.

Each of the four files contains a series of line segments defining the geographaical data. Each line segment in turn has a rank. For example, the coast, islands and lakes file has 12 ranks:

1. Coast, islands, and lakes that appear on all maps;

2. Additional major islands and lakes

3. Intermediate islands and lakes;

4. Minor islands and lakes;

5. Intermittent major lakes;

6. Intermittent minor lakes;

7. Reefs;

8. Salt pans-major

9. Salt pans-minor;

10. Ice shelves-major;

11. Ice shelves-minor;

12. Glaciers.

For the most part line rank is analogous to map detail. Thus by selecting certain line ranks, it would be possible to create maps of varying accuracy.

Since the WDB II contained data for the whole North American continent it was necessary to strip out those line segments defining the study region. At the same time the files organization was mofified, though not its basic line segment structure.

The data for the Great Lakes study area retains its basic line segment structure but it has been reformated into a standard FORTAN direct access file. The new file has a record length of 100 words and contains some 80,000 plus /minus records. This new file allows random access and this principle was incorpoated into some special software under development for the study.

SOME SPECIALLY DEVELOPED SOFTWARE

Because of the different data formats required by the various software used in the study, several small data conversion programs had to be developed. These programs are relatively simple and require no special reference here. However one new piece of software is worth mention. As it is currently configured, this new software manipulates and displays data from WDB II. At this writting, the program is not yet completed but is far enough along for inclusion here.

The World Data Bank Manager computer program is interactive and utilizes a special file, containing pointers, to access the WDB II direct access data file. Basically, the program querys the user on the area to be mapped, level of detail to be shown, scale necessary, and other related information (see Figure 4).

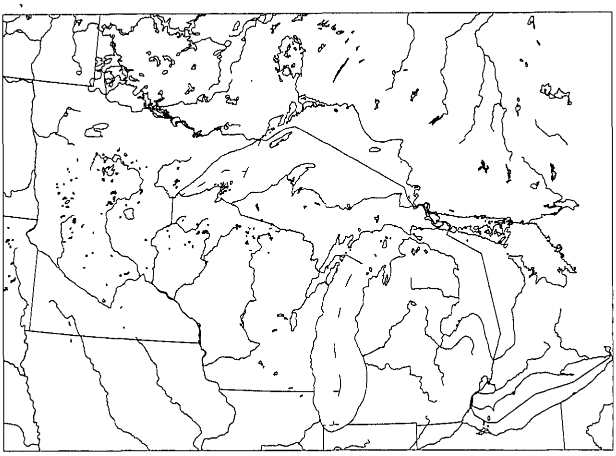

Figure 4: A Sample of Output from the Reformated WDB II

Using the input constraints, the pointer file is searched for the information needed to read the data file and map it. This direct access and pointer file logic has some advantages. For example, windowing is speeded up since the pointer file contains information on the location of each line segment string. Thus only those line segment strings which might fall inside the window are read and processed. This of course reduces cost since fewer computer resources are used. In addition the direct access uses computer resources more efficiently.

OTHER RELATED SOFTWARE

While the mapping software is the major focus of this paper, it is necessary to touch on two other areas of interest. The first is the data based management software and the problems revolving around it. A second area worth mention is the statistical packages in use or under consideration.

Currently the field data is being stored and handled in the SIR data base format (Robinson, 1980). However, while that was and still is the basic plan, some problems have developed with this decision. The first is the computer skill level of some of the project's staff. Unforunately, some of the staff has an insufficient understanding of computer data handling processess. Also, the version of SIR used to make the project cost estimates was a preliminary one and was subsquently withdrawn. Do to the inefficienties of the withdrawn version of SIR II, the cost estimates were very high and this raised the question of whether to change to a more cost effective data based management system. Cost, therefore, has become an issue in the debate as to whether to continue the use of SIR.

Several possiblities have been discussed. One solution would be to upgrade staff personnel so they would be truely conversant with SIR. This might take some time but it would mean that the data formatting would remain constant. Another possiblitiy would be to purchase or lease another data based management system. Finally, a proposal has surfaced to develop a unique data based management system for the study. At this time, no decision has been reached.

Recently some questions have arisen concerning the statistical packages. The three possible choices are SPSS, BMDP, and MINITAB and these all have been used for various tasks. The reason for using all three is that not all of the packages offer a complete selection of statistical procedures. Thus it is not possible to standardize on a single package. However, the question that remains to be answered, is if a select statistic (e.g. regression) generated for a set sample of data is the same regardless of the statistical package used. it. This question has not yet been resolved. Until it is, the only solution is to select a package for a certain task and always use it. Thus the statistics would always be comparable for very data set for all time periods.

CONCLUSION

While some of the problems outlined in the last section of the paper would not have occured if a comprehensive geographic information and analysis system had been used, other problems would probably have surfaced. Both the data base management and the statistical package problems seem to have resulted more from planning deficiences than any inherent unworkability. By definition, the use of a large number of independent programs, with no existing interfaces, does require much more planning than if one single system is used. Clearly problems still exist with the data base management and statistical programs but the problems are not insurmountable.

The mapping segment of the project has generated less problems overall. Part of the reason for this is that fewer staff were involved and their knowledge of the mapping programs was quite high. Thus it was easier to interface programs or to pick the right system for a given task.

While the project is not far enough advanced to say that no serious mapping problems will surface, it can be safely stated that none have come up so far. The methodolgy of using a number of mapping programs for a study such as this clearly causes some logistical problems but it appears a workable solution for this project. However, since no testing was or will be carried out using a large integrated geographic information and analysis program, this report cannot definatively say which research methodogly is best.

One thing shown by this paper is that a wide range of mapping programs can be used in a single comprehensive analysis. Thus while it might be desirable to use a large geographic information system, it is not always necessary.

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A NEW APPROACH TO AUTOMATED NAME PLACEMENT

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ABSTRACT

The Automated Name Placement research project was funded by the National Mapping Division of the USGS in September 1981. The purpose of this research project is to determine the feasibility of using computer technology to generate names overlays for map production. There are three components of a comprehensive name placement system: 1) A names data base, 2) type size and style selection procedures, and 3) the placement logic. The original proposal submitted to the National Mapping Division was divided into three phases: 1) creation of a test data base for point, linear and areal names, 2) development of techniques for automated placement of point names, and 3) development of techniques for automated placement of linear and areal names. Work is nearing completion on the first phase which included the creation of a data base of point names along with software to process user requests, select features and produce verification plots. Linear and areal features have also been entered in a second data base following the development of matching algorithms to correlate the names from the Geographic Names Information System (GNIS) with their digital representations from the National Atlas files. This paper discusses the procedures followed during the first phase of this research, shows examples of maps produced by the software and evaluates the future of this area of automated cartography.

INTRODUCTION

Time and space do not permit us to go into an extensive history of the lettering and name placement process. However, name placement has been quite troublesome to cartographers. Advances in technology have helped the map maker in every aspect of the mapping process except for name placement. With the introduction of computers, many cartographic procedures have been automated during the last decade. Name placement is the only process that has not had the advances seen in other areas of cartography. This is a significant problem since over 50% of map preparation time is spent on the name plate, in spite of the fact that various methodologies and procedures have been developed for the placement of names.

Why are we having such difficulty with utilizing computer technology in the name placement process? The answer lies in the complexity of the process and the restrictions of the computers. Although the speed of processing has increased tremendously during the last ten years, the "intelligence" of these machines is still the same. They are as intelligent as we can make them. If we examine the field of automated cartography, we can see that most of the procedures in existence have been developed by non-cartographers. These methods and procedures are straightforward and do not require extensive cartographic training. The name placement process, however, is more complex and does not yield to simple solutions. This is not to say that attempts have not been made. The literature is quite limited but Yoeli,(1) Wilkie(2) and Hirsch(3) are a few of the small group of people who have attempted to automate the name placement process. During the last few years more attention has been given to automated name placement and as we can see in this conference, the importance of the topic is being realized more and more.

We can classify automated name placement into three distinct categories: 1) fully-automated systems, 2) semi-automated systems, and 3) interactive systems. In the fully-automated systems all placement is done with computer processing. The developed software must check for overplotting, place names along linear and within areal features, decide which names to place and where. Semi-automated systems enable some manual interaction such as correcting problems resulting from cases improperly handled by the fully-automated systems. Interactive systems, on the other hand, give the cartographer full control of the placement process. This process is <u>not</u> an automated name placement process but a mechanized manual operation. Our goal is the fully-automated system, but reality for the time being is the semi-automated system.

Some research has been attempted at the fully-automated name placement process. The author's Ph.D. research has shown successful results and the present activity sponsored by the National Mapping Division has yielded good results, although still in its early stages. The present paper will describe the procedures involved in creating comprehensive names data bases, report on the status of the project, and discuss problems encountered and the future of the research.

RESOURCES FOR CREATING THE TEST DATA BASE

Currently, two major efforts are underway to collect comprehensive data for geographic and cartographic purposes. One of these which was described in the earlier paper by Roger Payne(4) is the GNIS effort and the other is the capture of digital cartographic data by the Eastern Mapping Center of National Mapping Division. This effort involves the digitization of the up to eight overlays of data from the 1:2,000,000 scale National Atlas sheets. There are several papers in this conference addressing this data.

These two data bases were the most comprehensive ones available and no user testing was done on either data base similar to the effort that will be described here.

The states of New Mexico and Arizona were chosen as the test area. At the start of the project, we received a file in the Digital Line Graph (DLG) format for this area with eight categories of data: political boundaries, administrative boundaries, roads and trails, railroads, streams, water bodies, cultural features and hypsography. Of these eight categories, the political boundaries overlay was used for outline and reference plotting, the administrative boundaries and water bodies overlays were used during area determination and the streams overlay was used to test the algorithms for linear features.

Three separate files were received from the GNIS data base for the test area: 1) a point names file, 2) linear names file, and 3) areal names file.

The point names file consisted of all populated places within the New Mexico-Arizona area which had been coded with the feature class definition of "ppl" in the GNIS. There were close to 700 names in this file and besides the latitude and longitude of the point, the file contained state and county FIPS codes and 1980 population.

The linear names file contained all the features with 'STREAM' as their definition. This yielded several thousand names with primary and secondary coordinates for each name. In a separate effort, certain stream names were captured for the 1:2,000,000 scale National Atlas sheets. This file contained 36 names.

The areal names file was also an extensive file with several thousand names. All names with feature class definition of "LAKE", "TANK", "PARK", "SUMMIT", "FOREST", "BENCH", "CEM", "CIVIL", or "AREA" were retrieved. This file contained state and county FIPS codes along with the latitude/longitude of the point.

The processing done to generate the two data bases is described below.

POINT NAMES DATA BASE

Name placement is straightforward if one does not worry about the number of names and the clutter on a given map. However, if a decision has to be made as to which names to place at a certain scale then a selection methodology must be devised. For the present research, the method outlined by Kadmon[5] was utilized. This method uses rank values and weighting. Rank values are assigned to the variables chosen to describe a point location. A final weighted rank is computed by multiplying each rank value by a weighted vector for a given case. The equation for n points with m rank values would be

$$R_i = \sum_{j=1}^{m} r_{ij} w_j \quad (i = 1,2...n) \tag{1}$$

where R_i is the final weighted rank vector, r_{ij} is the matrix of rank values and w_j is the weight assigned. Once the weighted ranks are computed, the selection consists of sorting these values and placing the top p values selected, where the value of p is assigned by the user or calculated using the scale of the source and output maps and the number of names contained on the source map. A selection criteria of this type is described in a paper by Töpfer-Pillewizer[6].

The point names data base created for the present research has seven variables associated with each name in addition to the place name and latitude /longitude values. These are: state FIPS codes, population, administrative, post office, bank, and trade ranks, and a remoteness factor. The names, latitude/longitude values and the state FIPS codes were taken from the file received from the GNIS. The place name consists of up to 24 characters stored in upper case because of the restrictions of the plotter utilized for testing. Population rank values were computed from the GNIS file of population values using the following rank assignments:

Rank	Population
0	None
1	1-1,000
2	1,001-5,000
3	5,001-10,000
4	10,001-50,000
5	50,001-100,000
6	100,001-250,000
7	250,001-500,000
8	500,001-1,000,000
9	Over 1,000,000

The administrative rank was assigned depending on the status of the place: 3 if National Capital, 2 if State Capital, 1 if County Seat and 0 otherwise.

The data for the post office, bank, and trade ranks was obtained from the Rand McNally Commercial Atlas. A value of 1 was assigned in the appropriate fields if a post office or bank exists at a given place. The trade rank is based on the total retail trade for a place in millions of dollars: 5 for over $1,000, 4 for $500-$1,000, 3 for $250-$500, 2 for $100-$250, 1 for less than $100 and 0 for none.

The remoteness factor in the data base was introduced to make it possible for seasonal, historic, remote and other significant locations to appear in certain maps. National Mapping Division personnel selected locations in the test area having these properties. A remoteness factor of 1 was entered for these place names.

Two programs were written to retrieve and verify the point names data. The first is an interactive program. It converses with the user to determine output scale, number of names to be placed on the map, the rank weights, minimum and maximum computed rank weights, output plotter type, political boundaries output and whether to file separate the output overlays. A file is created which is used by the second program to generate the plot. If the output medium is the Tektronix 4014, then a plot is generated automatically. Otherwise, the user must submit a job to be run using batch processing. Figure 1 shows an interactive session, Figure 2 shows the corresponding plot generated by the plot program.

LINEAR NAMES PROCESSING

The processing involved in creating the data base for the linear names was much more complicated. The GNIS portion of the processing consisted of examining the two files mentioned earlier. The file which was digitized from the 1:2,000,000 scale map was unsuitable because only one coordinate at the mouth of each stream was digitized. Therefore, it was virtually impossible to match any of these names with their line segments in the DLG files. To solve this problem, we decided to use the names from the 1:2,000,000 scale file to extract coordinates from the more detailed 1:24,000 scale GNIS files. Retrieving all coordinates associated with the 1:2,000,000 scale names from the 1:24,000 scale file gave us sufficient data for use in the matching process.

In a parallel effort, the streams overlay of the DLG file was processed. This file contained ramdomly digitized line segments which were topo-

```
ex anp.clist(getwts)
ENTER POSITIONAL PARAMETER FILE -
vs5095u.paper1
  THIS INTERACTIVE SESSION WILL ENABLE YOU TO SELECT
  CITIES FOR YOUR MAP.

  ENTER THE DENOMINATOR OF THE OUTPUT MAP SCALE:
5000000.


  FOLLOWING ARE THE AVAILABLE RANKING FACTORS IN THE DATA BASE
  WITH THE CORRESPONDING DEFAULT WEIGHTS.
  ENTER NEW WEIGHT OR A 'CR' TO USE THE DEFAULT VALUE:

  POPULATION (1) ?

  ADMINISTRATIVE (1) ?

  POST OFFICE (0) ?

  BANK (0) ?

  TRADE (0) ?

  REMOTENESS (0) ?


  AT SCALE 1 :  5000000 THERE WILL BE  251 NAMES IN THE OUTPUT MAP.
  ENTER NEW VALUE IF YOU WANT MORE OR LESS NAMES THAN THIS:
50

  ENTER MINIMUM RANK TO BE PLOTTED (1) ?


  ENTER MAXIMUM RANK TO BE PLOTTED (999) ?


  DO YOU WANT POLITICAL BOUNDARIES (Y/N) ?
y

  DO YOU WANT THE POLITICAL BOUNDARIES FILE SEPARATED (Y/N) ?
n

  TYPE OF PLOTTER:  1 = CALCOMP
                    2 = GERBER
                    3 = TEKTRONIX     (3) ?
1
READY
```

Figure 1

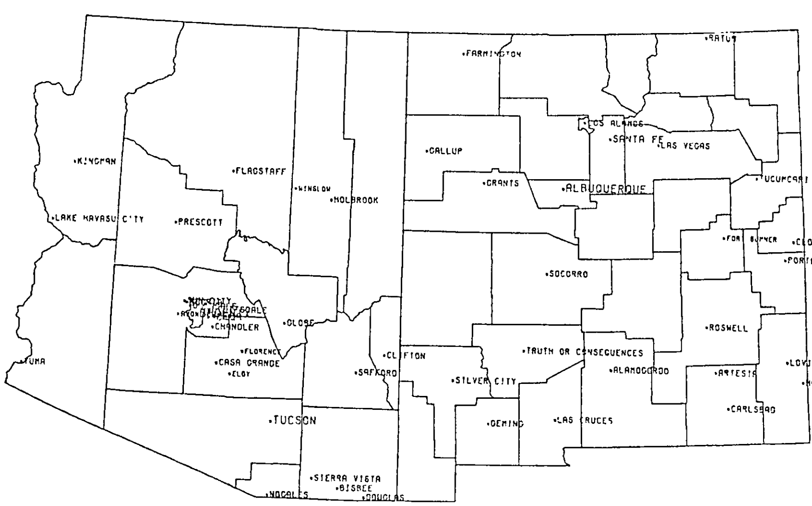

Figure 2

logically correct; that is, end points of each line segment matched the end point of the next line segment. As a result of this, it was possible to chain line segments to produce single lines representing a river or stream. This involved a computer intensive process of searching through the line segments to match the end points. Considerable knowledge of the DLG file structure and attribute coding scheme was required.

The final step of the linear names processing before building the data base, was the matching of the points from the GNIS files (those marked as '+' on the plot) with the coordinates from the DLG files (the line segments on the plot). The software written for this step checks the coordinates for each name against the coordinates of each line segment. The name is assigned to the line segment which contains the most matches within a given tolerance. Twenty-one names were matched correctly with their corresponding line segments within a 15 mil tolerance. These names were entered into the final data base.

AREAL NAMES PROCESSING

The processing for areal names again involved several different pieces of software. The first was a selection program which retrieved the areal names from the GNIS file depending on the specified feature class definition. In the first execution of this program a file for the water bodies overlay was created by selecting "LAKE" and "TANK" feature classes and the second execution created a file for the administrative boundaries overlay by selecting "PARK" and "FOREST" feature classes. Both of these files contained the name and the latitude/longitude coordinates as digitized from the 1:24,000 scale maps. It should again be noted here that the present effort is to test the software developed and any of these files could be expanded by selecting other feature classes or through numerous other techniques.

The administrative boundaries and the water bodies overlays of the DLG files are also topological files which make it relatively easy to create individual closed polygons of the areal features. This was done because closed areas will be required so that names can be placed within them if the scale permits and to identify the name for the present processing. Software was written to create these individual polygons and put the coordinates in a file by utilizing segment chaining operations.

Final processing of areal features involved matching the names from the GNIS file with the polygons created from the DLG file. Using point-in-polygon techniques, these comparisons were made and the names for which the identification point fell within the polygon were inserted into the data base.

The DLG polygon creation yielded 113 polygons for the water bodies. Point-in-polygon processing found 30 points from the GNIS file that fell within these polygons. Two of these polygons had multiple names within the area. This is due to the vast differences in scale of the two files. Coordinates for another 15 names were within a small distance of the closed polygon and these could have easily been included in the data base.

There were 282 polygons created for the administrative boundaries overlay. Only 33 polygons had points from the GNIS file within them and most of these had multiple names. This was followed by a manual checking process which showed only 10 of these to be correct. More research needs to be done in this area if administrative boundaries are to be included in the automated processing.

LINEAR AND AREAL NAMES DATA BASE

Following the above processing, a two level data base was created for linear and areal names. The first level contains the descriptive features: the name of the feature, a code indicating whether it is a linear or areal feature, the length of the line forming the feature (this value is in inches), the area of the feature for areal features (this value is in square inches), state and county FIPS codes where applicable, the coordinates of the minimum bounding rectangle, the number of coordinates forming the line segment, and a pointer to the second level. The second level is a "cartographic" data base; that is, it only contains the coordinates that form the line. Presently, the second level file is a sequential file. Figure 3 shows contents of this data base.

PROBLEMS IN CREATING THE DATA BASES

Attempting a research of this magnitude is a major undertaking. The data bases that were available are quite comprehensive. However, their contents and capacities were somewhat inadequate for this type of processing. Both data bases are sophisticated enough to handle many other requirements but unfortunately are lacking in attributes required if they are to be utilized by a name placement system.

Starting with the GNIS files, for the point names files, the population value alone is not sufficient as a selection criteria. Although it is difficult to include different types of data in these files, a value such as administrative status could easily be stored. Secondly, we found that several places with populations over 30,000 were missing from the files. This reflects the "age" of the file even though the population values were from the 1980 census.

The linear and areal names files had not yet gone through the final edit process and there were quite a few points well beyond the error tolerance. However, the overall quality of these files, especially the linear features, was quite good. The file for linear names that was digitized for the 1:2,000,000 scale map as a separate effort is almost useless for matching purposes. Identifying a single point at the mouth of a river and trying to match that point to a line segment in the DLG file is an impossible task. This file is useable only if manual matching operations are used between the two files.

The DLG files have other problems, the most significant of which is the lack of documentation. The processing on the linear features would not have been possible without several meetings with the USGS personnel on these files. Also, lack of vertical control between overlays in these files may be a problem later on in this research.

The problem that is unavoidable is the one resulting from the differences in scale. The over abundance of data from the GNIS files was most obvious in the processing of linear and areal features. Even after selection by feature class, there was still too much data.

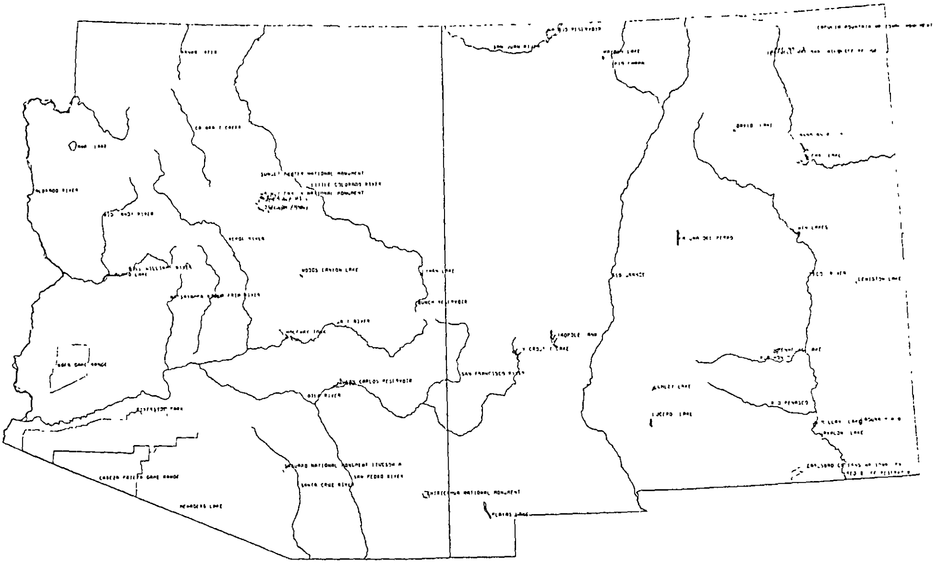

Figure 3

Figure 4

Identification of several names within a given area during the administrative boundary processing also points out this fact.

FUTURE OF THE RESEARCH

The creation of names data bases was the first phase of this research. The subsequent phases will deal with the actual placement problem. Prevention of overplotting of point names and features within an overlay will be the next step of the project. The algorithms developed during the author's Ph.D. research will be expanded to determine whether they are feasible in a large scale operation. The phase following this will be the development of software to place names within areal features and along linear features. The algorithms for these were also developed during the author's Ph.D. research. Figure 4 shows one of the maps produced utilizing those placement algorithms. The goal here will be to duplicate those results in a larger scale effort.

The future of the names data bases is quite promising. The effort so far has shown that two different data bases such as the GNIS and DLG can be manipulated successfully. Matching of names and lines for linear features was the most successful of these processes. More work needs to be done to produce improved results for areal features.

The data base attributes for point names were manually entered. Since Rand McNally stores its Commercial Atlas data in digital form, it would be feasible to acquire this data and write software to generate these files using automated techniques. The variable "remoteness factor" requires clearer definition and understanding. It is very difficult to quantify this variable and therefore to automate its generation process.

The topic of type size and style selection has been left out of this discussion because other research activities are addressing it and it is well beyond the scope of our present research. We feel that, for the present time, development of techniques for automated name placement outweighs the presentation of the type. This aspect of name placement will be improved by the time the placement techniques are developed.

CONCLUSIONS

In this short presentation an attempt was made to describe what has been done during nine months of research. By definition, research many times is a trial and error process. We have had our share of trials in this research so far. The diverse nature of the two data bases made this initial phase even more challenging and we believe this effort shows that even with the vast differences in scale of the two data bases, successful results have been achieved. This is especially true for the linear names. More linear features could have been identified if we had chosen to include more names from the GNIS files or used lower level classification attributes from the DLG files. Areal names processing unfortunately was less successful than we had anticipated for the reasons mentioned earlier.

As the present session of Auto Carto V shows, the interest in automated name placement is growing and the future looks quite promising.

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DATA SYSTEMS FOR WATER RESOURCES MANAGEMENT

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ABSTRACT

Water resources management decisions are facilitated by the use of well organized and readily available data. For the data to be converted to useful information, it must be analyzed and reviewed with the specific data needs of the users in mind, a task which is greatly aided by an appropriate data structure. Efficient water resources management is best achieved by using, as a foundation, data which are organized by hydrologic relationships. Easy access to current data is equally as important as appropriate structure. Thus, data storage and retrieval methods need to be capable of rapid update with sufficient flexibility to organize current knowledge in a usable format and response to availability of new data and changing data needs. Recently developed computer based water data systems are discussed. At the center is a hydrologic data base for the major surface waters of the contiguous 48 states. It contains unique identifiers and hydrologic connections for over 68,000 reaches. In addition to the river network, the data base contains the digitized traces of streams, lakes, coastlines and basin boundaries. The data base can be used as a framework for organizing water data and routing streamflow and pollutants through the nation's river systems. Linked to the file are a series of data modules including: ambient conditions, point source discharges and drinking water intakes. As the system is utilized, it is anticipated that new modules will be added. It is recommended that all the data modules be linked to one system to assure better data accessibility.

INTRODUCTION

The development of water data systems has been an on-going endeavor by water resources managers for at least 20 years. The impetus for the development of these systems comes from the growing concern for the quality of the aquatic environment and the concomitant increase in the demand for water resources, which have occurred in the past two decades. It has been realized that detailed, accurate and up-to-date information is a prerequisite for accomplishing any goal related to water resources management. The mandate to maintain and improve the quality of the nation's water, accompanied by the ever increasing demand for competing uses of that water has created a tremendous demand for data by those charged with managing water resources. The processing and analysis of such large amounts of data have inexorably demanded the use of automated information systems. Recent developments in computer technology, most notably the development of powerful data base management systems and the significant reduction in computer storage costs have created the potential for the development of very powerful national level water data systems. Some recently developed and developing water data bases, which take advantage of the new computer technology are described here.

It is easiest to define an information system in terms of its functions. Simply stated, a system performs the tasks of data storage and retrieval. The value of a system can be judged by how well it meets the information needs of its users, so a successful water information system design must reflect the unique nature of water data.

There are some general criteria which can be used to evaluate a system. One of the most important is the ease with which data can be stored and accessed. A water information system becomes more useful as more data is contained in it, but unless the addition and retrieval of data is made very easy not many groups will want to add their data to the system. Flexibility is also of prime importance in a water data system. Not only should the system be able to accept and output many different forms of information, but it should also be capable of change when it is required.

Another aspect of system quality, which is often overlooked is the quality of the data contained in the system. No matter how easy it is to access data or how flexible the outputs, if steps have not been taken to insure the quality of the data, the system will ultimately fail. An important part of any successful system is the quality assurance subsystem, which should at least include input standards, range checks, source codes and security measures to prevent accidental or unauthorized changes to data.

Steps can be taken at all phases of system development to ensure that a water data system will be useful. The system design must include data structures which are appropriate for the kinds of data to be stored and for the kinds of questions that will be asked. The data base structure should maintain key relationships between data types. Some of the most important relationships needed in a water data system are:

- Type of observation;
- Location of observation; and
- Time of observation.

With the data related in these ways, users can access data of specified types for a given area and time period. In a water data system, location should be specified in relation to geographic, political and perhaps most importantly to hydrologic frames of reference. Relating data to its location in the hydrologic system is important because it allows water data to be stored, retrieved and analyzed in the same framework from which it was originally taken. If all data is keyed to its location in a hydrologic frame of reference, where the links between the features are maintained, then the system can provide the ability to link observations hydrologically and to route information through the hydrologic network. For example, if water intakes were coded to the network, those facilities with intakes downstream of a toxic chemical spill could be quickly and easily found.

The key to maintaining hydrologic relationships is the existence of an appropriate river network, which facilitates coding data and permits simple upstream and downstream traversals of the network. For geographic and political location, there exist many suitable frames of reference which can be applied to an automated system. For river systems, there has not been a widely accepted framework developed for the entire nation. Recently SCS Engineers, under contract to the U.S. Environmental Protection Agency has developed what we believe can become the standard frame of reference for hydrologic data in the United States.

A COMPUTERIZED HYDROLOGIC DATA BASE

The Reach file contains the hydrologic structure for approximately 32,000 hydrologic features in the contiguous United States. These features are uniquely identified and divided into approximately 68,000 reaches. Features included in the file are rivers, lakes, coastlines and international borders. The Reach file was designed to be as simple as possible while maintaining unique identifiers and the linkages between features. Reaches in the file are identified by the USGS-WRC Cataloging Unit and a three digit reach number. For each reach, linkages are provided to adjacent upstream and downstream connecting reaches. During the original coding of the Reach file, the segment names were also codified and associated with reaches. This information forms the basic structure of the Reach file and it provides a very simple framework for locating and routing data. Updates are also easy to accomplish because linkages only affect adjacent connecting reaches. When a reach is added, only the linkages in the connecting adjacent reaches need to be updated.

The reaches were derived from the NOAA 1:500,000 Aeronautical Charts. The base maps were chosen to provide a file of minimum size that would nevertheless include most streams which receive direct discharges from pollutant sources and most streams which provide water supply for industrial, domestic and agricultural purposes.

In addition to the names and linkages and associated data contained in the hydrologic structure portion of the system, this system also contains traces of the reaches known as "trace data". Digitization of stream traces was accomplished using optical scanning techniques and automated line following procedures to transform the raster data generated by the scanning process into vectors which could be plotted to represent streams and lakes. Scanning was selected rather than digitizing for this effort because it was believed it would provide a more uniform and higher quality representation of surface hydrologic features. The resolution of this approach was about 150 meters.

This trace data enables users to obtain display of hydrologic data overlaying on the reaches in any area. It also permits the calculation of three types of reach length data. The first type is the length of each individual reach. The second type is the total length of all reaches upstream from the bottom of each reach. The third type is the length from the bottom of each reach to the mouth of the river through which it discharges to the ocean. The resulting mileage data may be used in a number of applications.

INFORMATION DISSEMINATION

In order to document the river network contained in this hydrologic file, a draft directory has been produced. This directory contains two basic types of information: first, tabular listings and second, plots of the stream traces. A sample listing of reaches in hydrologic order is shown in Figure 1.

Plots of the stream traces have been produced at 1:500,000 scale (see Figure 2). They include representation of the hydrologic features, labeling of each segment number, cataloging, unit boundary and cataloging unit numbers. Due to the scale of map used, it is expected that changes and corrections will be made. In addition, reaches are expected to be added gradually over time as specific needs arise for more detailed coverage in specific areas. Thus, frequent reprinting of the directory will likely be necessary (perhaps on annual or bi-annual cycles). Because of this frequent reprinting, maps were produced in single color only to save printing costs. The capability of the system and the equipment would readily permit the production of multi-color maps for specific limited applications.

The combination of listings and hydrologic feature plots will provide users with the ability to link their data to a common hydrologic framework such as is compatible with an automated storage and retrieval system.

AUXILIARY DATA

The universe of data for which hydrologic structure is appropriate is very large. Examples of the type of data linked to the Reach file include:

- Industrial wastewater discharge data, especially type of discharge and discharge quantity and quality;
- Municipal wastewater dischargers;
- Indirect wastewater discharge, that is, dischargers from industrial processes to municipal wastewater treatment plants;
- Surface water supply intakes;
- State reported fish kill events;

```
==BRANCHING PATTERN LEVEL== =TYP= ======SEGMENT NAME====== SEGMENT NUMBER   PATH   ARBLAT
  0   1   2   3   4                                                          MILE    MILE

   008                        S   LOYALNANNA CR             05010008-008   2176.8    8.2
   |
   |  009                     S   ROLLING ROCK CR           05010008-009   2175.7    7.2
   |/
   007                        R   LOYALNANNA CR             05010008-007   2168.6   21.8
   |
   |  006                     S   FOURMILE RUN              05010008-006   2177.4   15.2
   |/
   005                        R   LOYALNANNA CR             05010008-005   2162.2   67.7
   |
   |  005                     S   QUEMAHONING CR            05010007-005   2217.7   19.7
   |   |
   |   |  006                 S   STONY CR                  05010007-006   2223.9   25.9
   |   |/
   |  004                     R   CONEMAUCH R               05010007-004   2197.9   48.0
   |   |
   |   |  008                 S   SHADE CR                  05010007-008   2211.5    7.5
   |   |   |
   |   |   |  009             S   CLEAR SHADE CR            05010007-009   2214.2   10.3
   |   |   |/
   |   |  007                 R   SHADE CR                  05010007-007   2204.0   26.1
   |   |/
   |  003                     R   CONEMAUCH R               05010007-003   2195.6   86.9
   |   |
   |   |  010                 S   LITTLE CONEMAUGH R, N BR  05010007-010   2208.9   26.1
   |   |/
   |  002                     R   CONEMAUGH R               05010007-002   2182.8  149.2
   |   |
   |   |  013                 S   BLACKLICK CR, S BR        05010007-013   2190.7   15.6
   |   |   |
   |   |   |  014             S   BLACKLICK CR, N BR        05010007-014   2190.7   15.6
   |   |   |/
   |   |  012                 R   BLACKLICK CR              05010007-012   2175.1   51.6
   |   |   |
   |   |   |      016         S   YELLOW CR                 05010007-016   2183.4   21.8
   |   |   |     /
   |   |   |  015             R   TWO LICK CR               05010007-015   2161.6   28.6
   |   |   |/
   |   |  011                 R   BLACKLICK CR              05010007-011   2154.7   88.3
   |   |/
   |  001                     R   CONEMAUGH R               05010007-001   2146.6  252.6
   |/
   011                        R   KISKIMINETAS R            05010008-011   2131.5  321.8
   |
   |  010                     S   BLACKLEGS CR              05010008-010   2143.7   13.7
   |/
   004                        R   KISKIMINETAS R            05010008-004   2130.0  347.4
   |
   |  003                     L   BEAVER RUN RES            05010008-003       .0      .0
   |   L
   |  002                     S   BEAVER RUN                05010008-002   2124.3    6.3
   |/
   001                        R   KISKIMINETAS R            05010008-001   2118.1  368.3
```

HYDROLOGIC SEGMENT PLOT LEGEND FOR FIGURE 2

CATALOGING UNIT ------------ 05010007

REACH SEGMENT -------------- 012

SURFACE HYDROLOGIC FEATURE -

CATALOGING UNIT BOUNDARY ---

Figure 1. 1) Hydrologic segment directory -- hydrologic listing for cataloging units 05010007 and 05010008; and 2) legend for Figure 2.

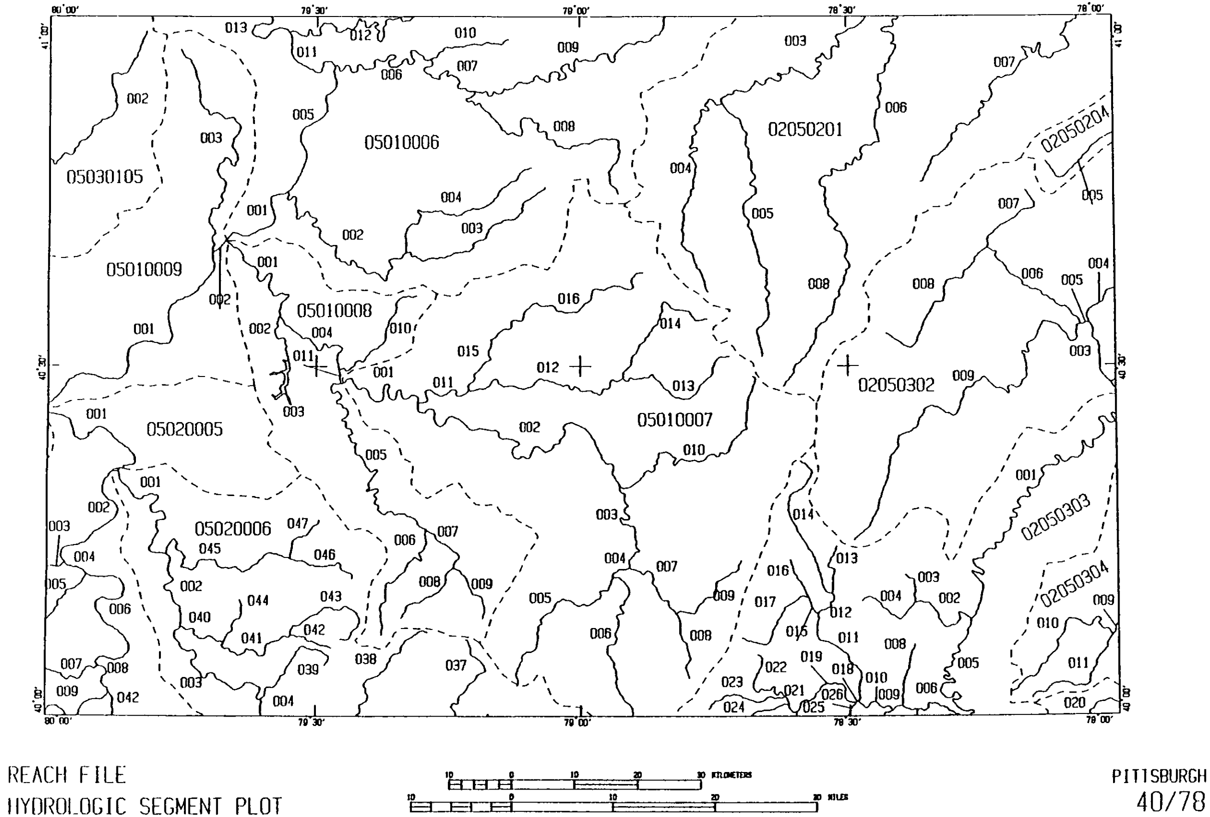

Figure 2. Hydrologic segment plot.

- Water quality monitoring stations and associated data;

- Stream characteristics such as flow, time of travel, bed material, bed slope, etc.;

- Fisheries classifications; and

- Eco-regions, (i.e., the general category of biological environment).

There are of course a wide variety of other types of data which would be appropriate for adding onto the file. Some of these data which are anticipated to be included at least for some selected geographic areas in the reasonably near future are:

- Land use and land cover data (beyond eco-region data);

- Meterological data, especially precipitation;

- Runoff quantity and characteristics data;

- Transportation (water born) data;

- Power generation statistics;

- Socio-economic data, especially population;

- Dam locations and operating rules/records; and

- Land disposal sites for waste.

APPLICATIONS

There are basically two categories of applications of this hydrologic system: those which have been implemented and those which may well be implemented within the next several years. In the first category, specific applications include:

- Strategic planning studies for industrial water supply;

- Inventory of water-related resources, especially fisheries information and water quantity data;

- Assessment of risks associated with pollutant discharges to support the development of controlling regulations;

- Water availability for power plant siting;

- Assessment of benefits derived from pollution control measures;

- Fisheries inventory;

- Studies of drinking water intake quality; and

- Studies of problem areas which may exist or develop (based on generalized input data for areas where detailed ambient monitoring data is not available).

In the area of potential applications, the list could be very long. Applications included below are those which seem to have the most likely potential for being implemented in the reasonably near future.

- Use of the system for storage and retrieval of water transportation data, especially barge traffic, and water-related statistics such as channel depth. In addition, it might be used to store and retrieve data on the types and conditions of various navigation-related structures and channel dredging projects to facilitate management or trade-offs in spending from one project to another as a function of need;

- Planning of water supply allocation and quality analysis, including the possibility for reuse of wastewater and its impact on availability and stream quality;

- Comparative studies of point and nonpoint-source pollution impact;

- Incorporation of ground water information, especially in areas of conjunctive use (with service water supplies);

- Area-specific analysis of land use impacts on water quality;

- Allocation of stream assimilative capacity;

- Analysis of new facilities siting feasibility;

- Tracking of pollutant discharge quantities with respect to applicable regulations to further simplify or maximize enforcement resources; and

- Response to emergency situations such as chemical spills, such that downstream water users could be notified of when they should shut down their intakes.

SUMMARY

Water data is required by many federal, state and local users and the creation and maintenance of a system to allow the sharing of data can improve the efficiency of all their operations by making access to data more convenient and by providing information in a form that facilitates analysis. There are various ways to provide a comprehensive water data system. One way is to establish a centralized data bank, which provides data and analytical capabilities to all users. Another possibility is to have a central core of data and many smaller systems for accessing and analyzing the data. A third possibility is to have a number of large data bases in various locations that can share data. For this to be a workable system, extreme care would have to be taken to ensure that the same data was identified identically in all subsystems. Each of the possibilities has advantages and disadvantages, so a study should be carried out to explore these and to make recommendations. Since the users of any comprehensive water data system would come from many different agencies, a decision on how such a system would be developed and maintained should be agreed to by all participating groups.

The technology now exists to provide a comprehensive national level water data system and recently some of the essential building blocks of such a system have been developed. The next logical step is to take the building blocks and develop a fully integrated water data system.

HARDWARE/SOFTWARE CONSIDERATIONS FOR OPTIMIZING CARTOGRAPHIC SYSTEM DESIGN

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BIOGRAPHICAL SKETCH

Paul D. Bell received a B.S. degree in Applied Statistics and Computer Science from Utah State University, Logan, Utah in 1967. He is currently serving as project director of the Advanced Cartographic Data Digitizing System (ACDDS) project, sponsored by the Defense Mapping Agency Hydrographic Topographic Center (DMAHTC). Mr. Bell has been involved with automated cartography in many aspects for over ten years, which include digitizing system design, implementation and support, as well as functional processing of cartographic line center and raster information. Previous experience includes systems programming and implementation for real-time data acquisition systems.

John A. Kearney received a B.A. degree in Computer Science from the State University of New York, Oswego, New York in 1978. He is currently serving as projector director of the SIGINT Support Facility/ Advanced Sensor Exploitation (SSF/ASE) Interface project sponsored by Rome Air Development Center (RADC). Mr. Kearney has previous software experience with automated cartography, interactive graphics, interactive and batch word processing, and Digital Landmass Simulation (DLMS) data.

ABSTRACT

An important goal in configuring and designing a hardware/software system is to attain a final product which utilizes, to the fullest extent possible, the baseline hardware and system software available to the developer. The Advanced Cartographic Data Digitizing System (ACDDS) has attained this goal while exhibiting an extensive range of interactive and batch cartographic data handling software functions. The ACDDS is a user-oriented system featuring: state-of-the-art hardware, reliability and maintainability, expandability, and future adaptability.

The design taken by Synectics Corporation to develop an advanced cartographic system for production use at the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) was to configure a cost-effective distributive computer network with a minicomputer host and satellite microprocessor based digitizing work stations.

TYPICAL REQUIREMENTS OF CARTOGRAPHIC SYSTEMS

The most important discipline of cartographic system design is understanding the user's requirements. By utilizing the technique of structured analysis, the user's requirements are defined and documented. As we all know, this is certainly easily stated, but rarely performed without some fuzzy requirement(s) surfacing. This fuzziness must be taken into consideration within the hardware/software design of your system. The typical requirements of cartographic systems that follow are founded upon the Advanced Cartographic Data Digitizing System (ACDDS) currently undergoing Operational Test and Evaluation (OTE) at DMAHTC.

Functional Requirements

The ACDDS design is based upon a subsystem concept. This allows for the optimized utilization of both human and machine resources. One subsystem (work station) supports acquisition/editing of cartographic data in an interactive graphic real-time environment, while the second (host) manipulates the collected data in a batch environment.

Work Station Functional Requirements

(a) Sign-On - provides the user with easy operational access to work station functions.

(b) Session Start/Station Initialization - provides the operator with easy entry of job chart parameter control information.

(c) Registration Function - correlates a chart on the digitizing surface to its actual position on the earth's surface.

(d) Header Build - generates a set of cartographic header description codes that are applied to digitized features.

(e) Executive Mode - operator controlled process scheduler and controller of the interactive real-time functional work station tasks.

(f) Trace Mode - records trace features (vector) by accepting X,Y coordinate pairs derived by the digitizing table and stores pairs into a feature data set.

(g) Depth Entry Mode - records bathymetric depth sounding feature data (X,Y depth) via keyboard or voice entry terminal.

(h) Discrete Point Mode - records single point feature information such as spot elevations, buoys, etc.

(i) Review Mode - graphically examines all features (trace, depth, and discrete point) collected within a job.

(j) Auxiliary Mode - changes parameter information used within a job such as display scale, graphic remarks, header build data, return to registration, etc.

(k) Edit Mode - allows the user to select a feature and affect some change. Edits include: file header update, feature header update, locate feature (X,Y; feature I.D.; geographic coordinate), feature reorder, trace feature edit, depth/point data edit, delete feature, and edit utilities.

(l) Help Mode - allows the operator to select "HELP" at any point during work station functions and explains select functions.

(m) Kill Function - allows the operator to escape from the present function and return control to previous mode of operation.

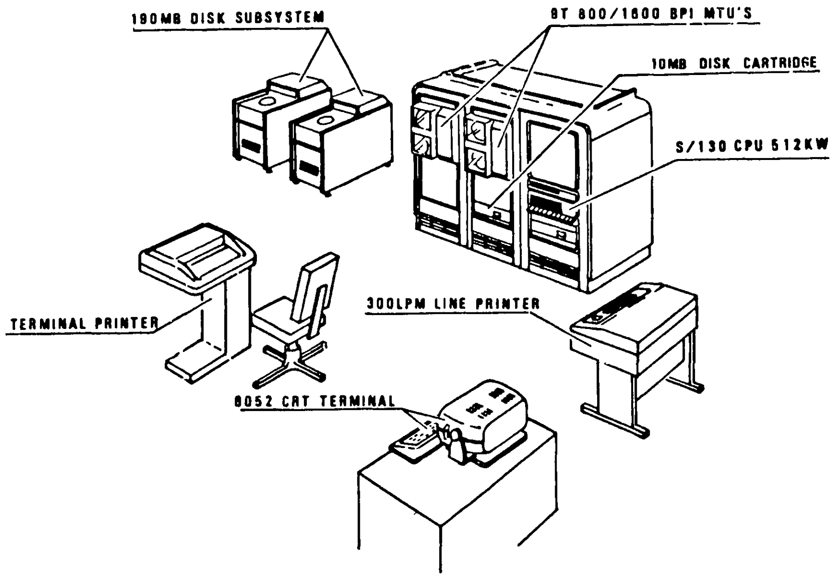
(n) Remote Job Entry (RJE) - makes available to the work station operator a means by which batch processing tasks may be submitted to the host processor.

(o) Send File to Host - transmits a work station data file to the host system.
(p) Work Station Diagnostic - allows the user the means of verifying that the work station hardware (graphic CRT, alphanumeric CRT, and digitizing table) are in operational order.

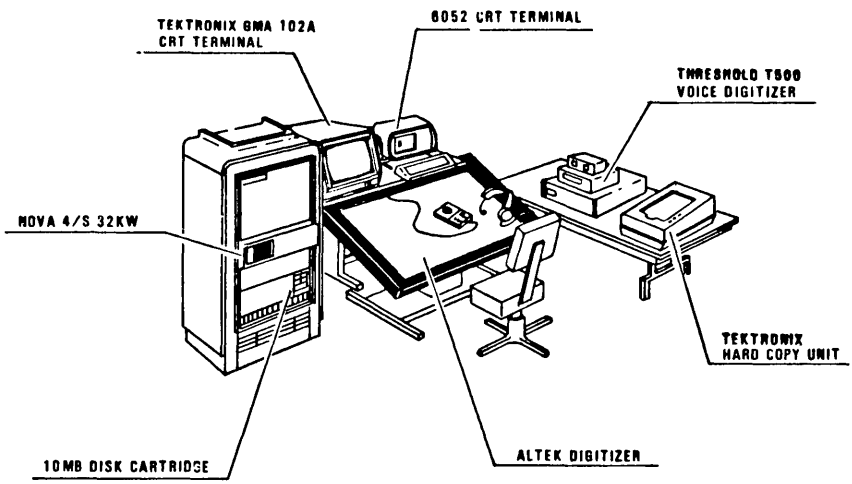
Host Functional Requirements.
(a) Magnetic Tape Input/Output - enables the transfer of geographic and table data to/from magnetic tape.
(b) Filter Data - filters a data file (geographic or table) to produce residual files containing accepted and rejected features.
(c) Merge - combines two disk feature data files (geographic or table) to form a third disk file.
(d) Format Conversion - converts Bathymetric Data Reduction System (BDRS), Lineal Input System (LIS), and ACDDS data (table or geographic) to any other system format.
(e) Unit Conversion - changes the units in which sounding depth data are stored to either feet, meters, or fathoms.
(f) Projection Transformation - converts table data to geographic data and geographic data to table data by utilizing the following projections: Mercator, Transverse Mercator, Lambert Conformal, Polyconic, Polar Stereographic, Albers Equal Area Conic, and Gnomonic.
(g) Sectioning - segments a geographic or table file.
(h) Paneling - butt joins two feature files which share a common boundary and creates a single disk file.
(i) Symbolization - symbolizes lineal and point features in accordance with symbology specifications defined by DMA.
(j) Plot - produces an accurate proof plot or symbolized plot on a Xynetics or Calcomp plotting system.
(k) Table File Update - generates all required files necessary for work station functionality from an input data file.
(l) Checkpoint/Restart - stops and restarts a batch function in the middle of an execution.
(m) Host Utilities - prints ACDDS table or geographic files, builds/prints - filter files, symbolization specification files, etc.

Hardware Requirements.
It should be noted, that without clear limits and priorities on size, performance, price, and functional requirements, unnecessary enhancements creep into the cartographic hardware design. After several iterations of "creeping elegance" the hardware no longer meets the original design objective. On the other hand, contingency plans should be designed into the system that encompass the "fuzzy set" and growth requirements. Following is a brief overview of typical hardware requirements for workstation and host cartographic subsystems, as depicted in Figure 1.

Cartographic Work Station Hardware Requirements. Common to cartographic work stations is a hardware configuration similar to the ACDDS which consists of: Data General NOVA 4/S Computer with 32K 16-bit words of memory, Floating Point Processor, 10MB Disk (5MB fixed - 5MB removable), Universal Line Multiplexor - Communication, Data General 6052 Video Display Terminal with keyboard, Altek Corporation DATATAB back lite digitizer, Tektronix GMA 102A 19 inch Graphic CRT and



ACDDS HOST HARDWARE CONFIGURATION



ACDDS WORK STATION HARDWARE CONFIGURATION

Figure 1.

controller, and Voice data entry terminal (Threshold Technology T500).

Cartographic Host Hardware Requirements. The ACDDS host hardware, typical of most cartographic systems, is comprised of: Data General ECLIPSE S/130 computer with 512K of MOS memory (16-bit word), Floating Point firmware, I/O Expansion chassis, 60 CPU Terminal Printer, Data General 6052 Video Display Terminal, Magnetic Tape Units (two 800/1600 BPI), 190MB Disk Unit (two), 10MB Disk (5MB fixed - 5MB removable), Data General 300 LPM Printer and Communication Chassis.

System Software Requirements

One might ask, what are some general requirements of system software that cartographic systems must have? These requirements are addressed in two areas, work station and host.

Work Station System Software. The system software running on the ACDDS work station is Data General's Real Time Disk Operating System (RDOS). The features of this operating system easily accommodate cartographic work station system design. They are as follows: supports real-time operation, easy system generation and tailoring with system tuning capability, easy interfacing of foreign peripherals, dynamic system buffer input/output, multitasking, intertask communications, program segmentation, device interrupt service capability, high level language processors with optimized code generation, provides communications for RJE, and system utilities.

Host System Software. The host system supports batch processing functional requirements. Within the ACDDS, the host system utilizes Data General's Advanced Operating System (AOS) which supports batch and real-time processing demands of cartographic systems. AOS capabilities include multiple batch job stream concurrent with real-time operation, multiprogramming processes, multitasking within each process, intertask and interprocess communication, easy system generation and tailoring, communication for RJE, high level language processor with optimized code generation, and system utilities.

Throughput Requirements

Now let us discuss the requirement of work station and host system throughput. Many times this requirement is fuzzy, implied, or not stated causing problems of acceptance of a system. For an optimized design of a cartographic system, this requirement must be clearly defined and understood. Typical throughput requirements similar to the ACDDS are discussed below (reference Figure 2).

Work Station Throughput. Session Initialization, consisting of chart and parameter control information data entry, header build, and registration data entry, should be achieved in less than five minutes as demonstrated on the ACDDS. A manual lineal data capture rate of 100 lineal inches/hour, with a target of up to 500 lineal inches/hour, was an ACDDS requirement. A capture rate of 491 lineal inches/hour was achieved. Computer-assisted (voice data entry terminal) depth data capture of 500 depths/hour was also an ACDDS requirement. The achieved rate of 949 depths/hour was demonstrated. The ACDDS also demonstrated a depth data capture rate of 1147 depths/hour via manual entry, against a requirement of 200 depths/hour.

Host Throughput. The number of functions executing simultaneously for a typical host system are two or more. The ACDDS can handle up to 20 functions simultaneously. The throughput requirements of

FUNCTIONS EXECUTED:	
• PROJECTION TRANSFORMATION	• PANEL
• UNIT CONVERSION	• TAPE I/O
• FORMAT CONVERSION	• PLOT
• SYMBOLIZATION	• MERGE
• SECTION	• SORT

	TIME	FILE SIZE	NUMBER OF FUNCTIONS EXECUTING SIMULTANEOUSLY
THROUGHPUT REQUIREMENTS	1 HOUR	2400 LINEAL INCHES	MINIMUM OF 2
DEMONSTRATED CAPABILITY	55.3 MINUTES	2410 LINEAL INCHES	4

ACDDS HOST THROUGHPUT

FUNCTION	REQUIRED THROUGHPUT	DEMONSTRATED CAPABILITY	ACHIEVEMENT BEYOND REQUIREMENT
MANUAL LINEAL TRACE	100 INCHES/HOUR	491 INCHES/HOUR	391 INCHES/HOUR
COMPUTER-ASSISTED POINT ENTRY	500 POINTS/HOUR	949 POINTS/HOUR	449 POINTS/HOUR
MANUAL POINT ENTRY	200 POINTS/HOUR	1147 POINTS/HOUR	947 POINTS/HOUR

ACDDS WORK STATION THROUGHPUT

Figure 2.

processing one run of each host function against 2400 lineal inches of data within an hour time frame was the requirement for the ACDDS. The demonstrated throughput was performed against 2410 lineal inches of data within a 55 minute time frame.

SOFTWARE REQUIREMENT CONSIDERATIONS

Previous sections have already discussed hardware and system software requirements common to cartographic systems. It is of paramount importance that these requirements be analytical while giving special consideration to the application software design and development needed to meet the functional requirements. Thus, the expenditures allocated to the areas of hardware, system software, and application software must be properly balanced to provide a cost-effective means of meeting the requirements of the end user. The ACDDS exemplifies a system which was designed and implemented along these guidelines.

Work Station Software

To provide cartographic functionality, an efficient, yet relatively inexpensive work station hardware configuration should be selected. For program execution, the ACDDS work station processor features a total of 32K words of unmapped memory. The operating system that was tailored for this configuration occupies approximately 11K words of memory. Therefore, about 21K words of memory were available for application programs.

At first look, it appears that the work station hardware configuration may be insufficient to handle the extensive array of software functions discussed earlier. In fact, collectively, the work station real-time application programs require slightly over 100K words of memory in which to execute. But the work station functions possess two qualities which make various means of program segmentation quite feasible: work station functions are extremely interactive in nature, that is, they don't require the rapid speed of number crunching batch processes; work station functions are logically independent, the only link that these functions have to each other is that they often require access to common job files on disk.

The application software exploits, to a great extent, the capabilities of the operating system to permit such techniques as multitasking and program segmentation. A multiple task environment is one in which logically distinct tasks compete simultaneously for use of system resources. Multitasking is particularly useful in an interactive environment to effectively permit several functions to operate concurrently. This technique, along with three methods of structured program segmentation discussed in the following paragraphs, provides the tools required to execute the work station software functions in approximately 21K words of physical address space.

Chaining allows the programmer to write a large program in a sequence of executable segments where the end of each segment invokes the beginning of a subsequent segment. Chaining operates at only one level and RDOS does not save a core image before bringing a new program into memory and executing it.

When a program swap occurs, the operating system saves a core image of the current program on disk and then brings a new program into memory for execution. The new program may then swap to a lower level or simply exit to allow the calling program to be restored from disk and resume execution. RDOS permits program swaps to occur in up to five levels.

The work station application software also makes use of a more common form of program segmentation called overlaying. Overlaying is used to further segment programs which are still too large for the 21K physical address space.

Host Software

The host hardware, typical of cartographic systems, is configured with large amounts of memory and peripheral storage. Also present is a sophisticated operating system with both multitasking and multiprocessing capabilities. By exploiting these features, the ACDDS host application software makes it possible to manage many complex processes simultaneously. A 'front-end' process constantly monitors all job request communications from both the work stations and the host. At the same time, an 'executive' process manages and controls the host batch environment by executing cartographic functions as requested by the user. Since these functions are logically independent of each other, they can be performed concurrently. With the present ACDDS memory configuration, five batch jobs can execute in main memory at one time. If more are added, some become blocked or swapped out of memory.

Other facilities of the operating system utilized by host application software include shared memory pages. The capability of reading a common or 'shared' memory location makes it possible to effectively checkpoint an executing batch job. Upon user request, this job can be swapped back into memory and restarted from its breakpoint.

The point to be made within the software requirement area, is that an extravagent hardware configuration is generally not required for systems such as the ACDDS. A modest amount of software effort to exploit the available hardware and system software resources should be invested to avoid overscoping the hardware requirements.

HARDWARE/SOFTWARE EXPANDABILITY CONSIDERATION

As stated earlier in this paper, contingency plans should be designed into the cartographic system for expandability. By making the expandability feature a priority item within the initial design of the system, the hardware and application software areas become somewhat protected from short and medium term obsolescence.

Hardware Expandability

Each component within the hardware design phase should be looked at for expandability and each area documented. Within the ACDDS hardware design, the following expandability contingency considerations are available.

Work Station. Hardware expansion on the work station can include: upgrade of the Data General NOVA 4/S computer to a NOVA 4/X supporting 128K words of MOS memory, expansion of the 10M byte disk subsystem to include three additional drives, addition of a magnetic tape subsystem if future requirements dictate, and addition of a voice entry terminal to the work station CPU with no internal hardware modifications.

Host. Upgrade of the ACDDS host system could consist of: enhancing the host Data General ECLIPSE S/130 to a Data General ECLIPSE S/140 or S/250 CPU, expanding the 190M byte disk subsystem from two to four disk drives, expanding the magnetic tape subsystem from two to eight tape units, expanding the synchronous communications to provide a high performance interface to the work station communications and expanding the 10M byte disk subsystem from one to four disk drives.

Application Software Expandability

Early on, within the ACDDS functional design phase, the "hooks and handles" for functional expandability were made available by utilizing the structured approach to cartographic design. This approach dictated modular software that could easily be used between work station and host functions. These common modules include: file input/output routines, data pack and unpack routines, parameter naming conventions, etc. It should also be noted that by utilizing this approach, software corrective and adaptive maintenance efforts are minimized.

Work Station. By utilizing the RDOS operating system's features and the work station's module applications software design, additional functions may be added in an easy manner. RDOS swaps, chains, and overlays can be efficiently used to add additional capabilities with virtually no software modifications. Each program swap, chain, or overlay was designed as an independent functional module with new modules being developed with this same criteria.

Host. The strong features of the host's ECLIPSE S/130 Advanced Operating System (AOS) makes available an intelligent multiprogramming system. This, combined with the modular host system control and applications software ensures for an early expandible software system. To add a new application, one must only modify the remote job entry module and a single routine within the control software.

CONCLUSIONS

The intent of this paper was not to teach you how to optimize cartographic system designs, but rather to demonstrate that there is no magic related to this process. The designer must be aware of the global design requirements of the system within the hardware, system software, and application functional software areas. He must know the limits and capabilities of his selected hardware, be extremely knowledgeable of the system software and its' usage, and of course, know his cartographic applications. Thus, he must know his cartographic design requirements, for a brilliant solution to the wrong problem will not do any system designer much good.

ACKNOWLEDGMENTS

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EURO-CARTO I*

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ABSTRACT

Euro-Carto I was a small (60 strong) scientific seminar held in New College, Oxford, from 13-16 December, 1981, under the aegis of Commission C (computer aided cartography) of the International Cartographic Association and with the support of the Royal Society. Euro-Carto II is planned for Oslo in March 1983. The paper describes the broad aims of the seminar and discusses some aspects of its scientific programme - hydrology, vegetation mapping and computer science. Each of these subjects seems to open new perspectives to cartography beyond the function of "mere map making" and into the uncertain but inevitable territory of geographical information systems.

Of the 750 participants in Auto-Carto IV in 1979 at Reston, Virginia, only about a dozen came from European countries. There is no doubt of the wide American interest that the Auto-Carto meetings generated during the 1970s both in the surveying and mapping community and also among those for whom cartography is at best only a subject of secondary interest - e.g. the US Public Health Service. I pay tribute to the continued success of these meetings.

The case for organising somewhat similar meetings in Europe was attractive because of the width of European cartographic experience, because of high levels of European technology in hardware and even more in software, and because of some Anglo-Saxon claims to have originated the notion of automated cartography at the ICA meeting in Edinburgh in 1964.

The plans for Euro-Carto I quickly took on their own idiosyncrasies. In the first place the meetings were to be on seminar lines with a maximum of audience participation; in the second place meetings were to address the sharp end of the subject - i.e. research - and to be more concerned with what we ought to be doing than with our current practice. And implicit from this was the need to keep meetings small and select (about 50). The intellectual nature of the discussions was underlined by holding Euro-Carto I in the rigorous atmosphere of a 14th century Oxford college in mid-December 1981 - it turned out to be the snowiest December for a hundred years.

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*Euro-Carto I was a small scientific seminar held in New College, Oxford, from 13-16 December, 1981, under the aegis of Commission C (computer aided cartography) of the International Cartographic Association and with the support of the Royal Society.

In the event - and despite both the snow and the pressures of recession on travel budgets - we had rather more than our ceiling of participants, and about half came from abroad*. Each of the chairmen of our four sessions were internationally well known - Joel Morrison of Wisconsin University and a vice-president of ICA, Hans Liebscher of the Federal Institute of Hydrology in Coblenz, Duncan Poore of the Dept. of Forestry at Oxford and formerly Director of the British Nature Conservancy, and Stein Bie of the Norwegian Computing Center. The proceedings of the seminar are currently in the press and will be published in October; they contain the "core papers" distributed six weeks beforehand to those attending the seminar - plus those papers presented at or after it. Publication - at $7.00 - is by the Canadian organisation Cartographica who will by this gesture have gone some way to making up for the absence of Canadians at the Oxford meeting.

Euro-Carto II is scheduled for 1983 and in Norway with Dr. Bie in the lead role - and already there is talk about Euro-Carto III. In a sense these cries of "encore" are gratifying; on the other hand there are dangers in the event becoming institutionalised into a kind of "club" and losing the stimulus of innovative scientific drive. Doubtless these issues are all too familiar to the organisers of nearly a decade of Auto-Cartos.

SCIENTIFIC PROGRAMME

I referred earlier to the idiosyncrasies of Euro-Carto I and have briefly described some of the administrative ones. Another idiosyncratic element lay in the subjects selected for discussion - hydrology, vegetation mapping, and computer databases. In selecting them we were concerned to emphasise the relevance of three scientific disciplines - hydrology, ecology and computer science - to surveying and mapping, and especially to the architecture of national databases or geographical information systems from which all kinds of maps - topographic and thematic - can be derived. The Oxford meeting placed unusual emphasis on the need for dialogue between cartographers and specialised scientists so that digital topographic data accumulating in databases can be structured to enable it to be used for more than "mere map making", and at the same time to improve the content and logic of maps. Our three subjects were of course only intended as examples of the interface between disciplines that environmental science demands: many others would have been just as appropriate. Our meeting was essentially for those with an appetite for geographical information systems.

Let us look in more detail at the three subjects that we selected for discussion.

Hydrology

An introductory paper for this session drew attention to the significance of the stream network (and its associated elements such as lakes) in topographic mapping: this has been assessed as being about 20% of the entire information content of the map. Furthermore rivers possess a high degree of internal topological organisation, and unlike many other line work elements in topographic maps are in reality a

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*Attendance figures were (a) Foreign: France 3; Finland 1; Germany 5; Italy 1; Netherlands 2; Norway 5; Poland 1; Spain 3; Sweden 2; Switzerland 1; USA 3; (b) UK: Academics 14; Commerce 6; Nature Conservancy/Soil Survey/Water resources 5; Natural Environment Research Council 4; Ordnance Survey/Military Survey 3.

highly structured entity. Despite this structural regularity inherent in river networks, the majority of applications of automated cartography treat rivers as if they were completely non-structured arrays of lines. Typically, digitised rivers have in the past been coded simply to show that they are rivers; they are generally discontinuous under bridges; and the direction and sequence of the digitising of individual stream links is often quite random. The cartographic approach to storing digitised river data as "spaghetti" can to some degree be defended as being adequate for straightforward map making; but such a disregard for structure makes it much less easy to re-use this topographic data for many specific tasks important to hydrologists, e.g. fast retrieval of all lines upstream of a particular stream link. In addition the incorporation of hydrological data in a structured fashion can make maps themselves more objective and consistent; the omission of rivers on smaller scales can, with this kind of forethought, be rapidly and rationally retrieved. The kinds of incidental inconsistencies that do occur at present between scales, even in high grade topographical map series, show up in variations in stream lengths or in the rationality - generalisation rules if you like - for omitting rivers at smaller scales.

In many countries there are already available several criteria which can provide more informative large scale maps and be the basis for a consistent and objective generalisation for smaller scales. One set of criteria relates to discharge characteristics as measured at gauging stations (thus mean flow, peak flow, specified recurrence interval, exceedence flows). Another set of criteria relates to biological and chemical aspects of river systems and to data on water quality - a matter of considerable environmental significance. A third set relates to morphological characteristics of the rivers involved (width, depth, profile downstream, capacity, stream order, area of catchment basin). Of these criteria the biological and chemical data are not as yet very widely sampled; however data on discharge does seem to exist, e.g. for most of the main rivers of Europe, though not for small streams - but even here measurements of precipitation can be linked with morphological characteristics to provide estimates of discharge. And many of the morphological characteristics are direct derivatives from the topography and the hydrologist generally has no alternative source than the topographic map from which to obtain them. These criteria all produce attributes that can be associated with digital segments (links between nodes) of the river system - and when associated can be used for example to extract all the network above or below a particular point at which a pollution event has taken place.

One method demonstrated by a British firm - GDC - is illustrated in Fig. I. The river patterns were digitised ensuring their continuity beneath bridges and producing a continuous link and node system in a straightforward manner. (It is convenient if all links do run in a consistent direction - up or down stream - but operational conditions, editing-in of revisions etc., sometimes make this difficult, nor is it essential at this stage.) Such data were then automatically structured and coded by climbing up the network within the computer - a powerful CDC one. A start is made from a specified point - e.g. the mouth of a river, and at any junction or confluence the search process turns right allotting a new code until it reaches a node with no other link than the one along which it has moved. It then does an about-turn and proceeds as before but noting those segments along which it has already passed and to which it has allocated unique codes. By a process of keeping track of code numbers allotted this programme can produce a plot on which every link has its own unique logical code number plus

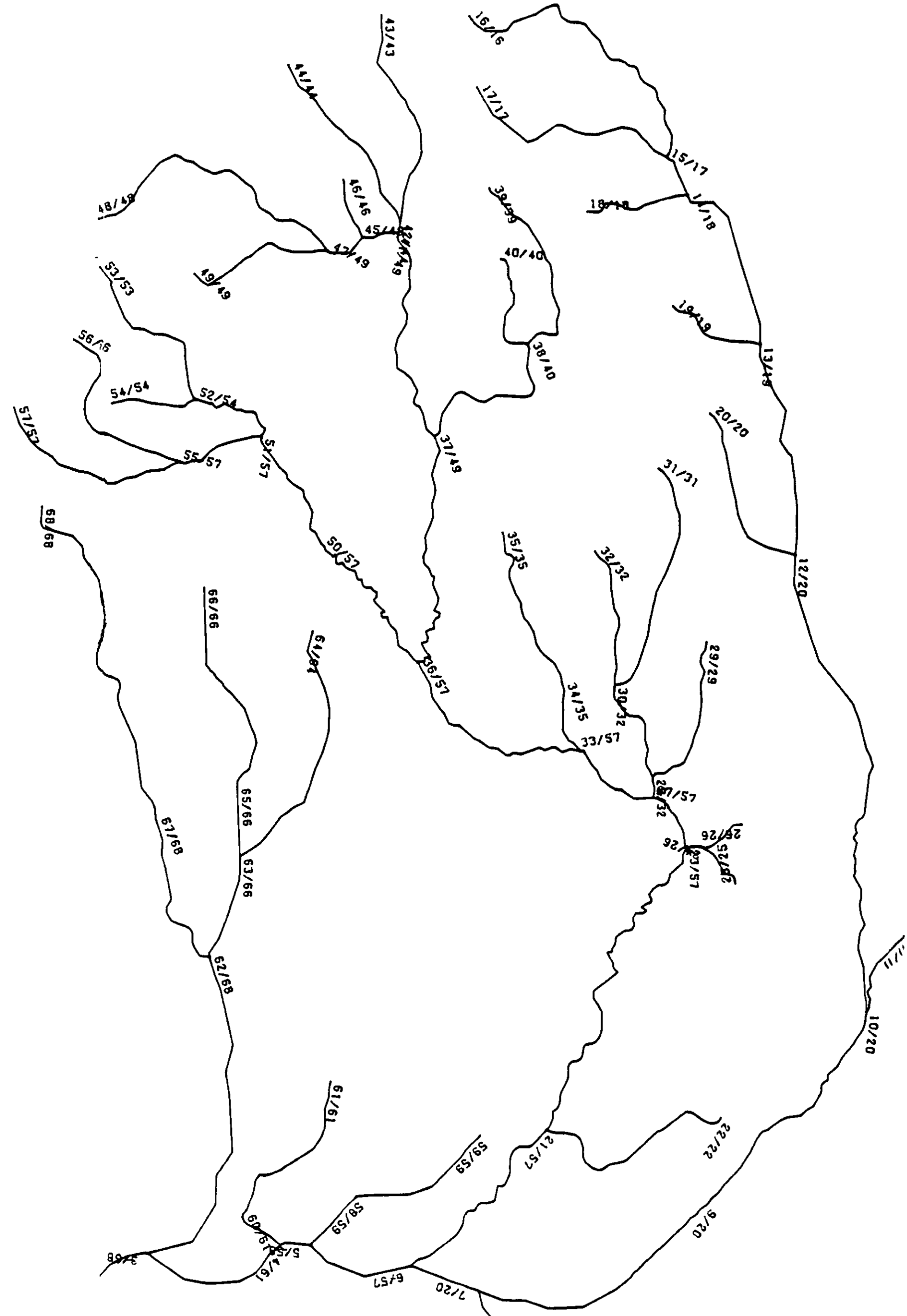

Fig. I

Stream Numbering by climbing up river network inside computer (Wyre Catchment, England. Scale 1/50k) the total of the links in the system. Granted such a labelled set of links and nodes, digital data about stream flow or biological characteristics can be easily added to the system. And of course first order, second order etc. streams can be identified (and may be useful for subsequent generalisation).

This process of structuring topographic river data has been demonstrated by examples published in the proceedings of Euro-Carto I: admittedly it demands a computer powerful enough to hold all the segments of a network in core. Beyond this of course it demands complete river systems in digital form (or at least upstream of the starting point if this is not the mouth of the river). Topographical map sheets are of course liable to include segments of different river systems and not to include all the segments of any one river system, so the process of automatic structuring/coding has to be applied to blocks of maps that have already been digitised. Other practical complications are in the treatment of double line rivers and the need to obtain a structural centre line in addition to both banks.

These small examples help to focus on issues that could at minimal cost increase the potential of the cartographic database and furnish usable information of relevance to specialised hydrologists. The information that topographers gather has uses - and even markets - beyond map making if structured with such logic in mind. So do we not need to escape from our present tendency to produce digital spaghetti? This is not perhaps an entirely academic issue. There seems over the last six months since the Oxford meeting to have been some recrudescence of proposals for digitising the river systems of Britain for the separate Water Boards that are the official authorities for rivers. The scale suggested is 1/50k though there is some case for using the more complete stream pattern from the 1/25k series. If schemes of this kind move ahead how do they relate to the work of topographic surveying carried out in Britain by the Ordnance Survey and generally at much larger scales (1/1.25k, 1/2.5k, 1/10k). These questions have not of course been answered - but it is important that they should at least be asked.

And the desirability of structuring river networks provokes related questions some of which were demonstrated at Euro-Carto. Many hydrologic problems need other elements of the topography such as contours to define catchment boundaries, or land cover as a factor in run off. As hydrology becomes increasingly computer based so the demand for digital cartography will grow if topographic data is structured and organised for both map making and use by other scientific disciplines. There is also a growing EEC interest in ecology and in attempts to control chemical pollutants in the rivers: at whatever scale this problem is considered it is likely that the digitising and structuring of river data will be involved. A separate point was covered by a Swiss demonstration plot - part of a 1/500k database of that country - which drew attention to the fact that administrative boundaries often coincide with rivers - and even banks of rivers - and often require defining and mapping at larger scales. For the cartographer river importance, traditionally expressed by thickness of line, is based on many factors of which mean flow is one.

Vegetation mapping

In this session it was evident that rather the same kind of overlap of interest between topography and hydrology also seems to exist between topography and ecology. All topographic maps find it necessary to display "vegetation", partly because they help the map user to see where he is and partly because they help to characterise landscape. Vegetation maps by contrast are often the work of specialised botanists using very detailed classifications which relate little to the topographic categories which they overprint. A wide new interest in natural habitats, in competing land uses and in change in the landscape seems to be developing. The new class of map user, the "land manager", seems likely to need rather more professional definitions of vegetation than he finds on topographic maps - and, by implication, will find in a cartographic database. We were again concerned that some growing together of these two disciplines is desirable, and in passing we observed that a computer database can obviously accommodate a very detailed classification structure from which it can easily and rapidly amalgamate classes - e.g. on an hierarchical basis - where such generalisation is required. The present situation where the topographer's definitions of vegetation - e.g. of marsh - are often unrecognisable by botanists and ecologists seems at best untidy and a potential source of confusion in a national database.

The discussion of this issue at Euro-Carto was illuminated by Swedish examples of vegetation mapping at 1/100k and 1/50k scales from Prof. Wastenson whose work at the University of Stockholm is funded by the Swedish Environmental Protection Agency. In his work he employs the full range of contemporary technologies from Landsat interpretation to automated cartography. Encouraged by this, a joint British/French project - an "Eco-topographical" experiment - has been undertaken. This uses the results of soil mapping interpreted to provide 72 vegetation classes on a phyto sociological basis and capable of generalisation (i.e. collapsing) into 18 groups in Britain. The classification is based on 20 years' work in the Soil Survey of Scotland. The experiment also takes particular topographic patterns from the OS 1/50k series such as rivers, contours, boundaries, built-up areas and communications. Both topographic and soil/vegetation patterns have been digitised by the raster system at IGN Paris - the System Semio - which has many common elements with the raster system e.g. at USGS. The result of this project seems to have induced some re-awakening of interest in ecological mapping in Britain - partly at least because of dramatically lower costs from the raster system and partly because of a whole range of area manipulation or "overlay" procedures which are easy to perform by raster working. The ability to measure the areas of particular vegetation types within a Nature Reserve and on a slope of over 12° - and doing so instantly and cheaply - provides a quite new flexibility for the scientific map user. Their very cheapness does seem to give promise that they may actually be used.

Quite apart from the technical interest in this Anglo/French experiment it is encouraging to see progress in international collaboration actually being realised within six months of the Euro-Carto seminar. We are not resting on our laurels in this respect.

Computer Science

The first introductory session of our seminar consisted of a paper by the Director of research of Univac - Dr. Michael Godfrey. His review of the directions that computing seems likely to take over the next five years was illuminating and especially so since he had had close connexions with my Experimental Cartography Unit during his previous academic career in London. His references to VSLI systems (very large scale integration) with c. 10^5 logical devices operating at a speed of 0.5 MIPS (million instructions per second) but only costing $200-300 were interesting. They give the prospect of very powerful processing being cheaply available and being portable enough to take to large environmental data sets - rather than the reverse. Does this imply an unprecedented decentralisation in computer cartography? Shall we find ourselves processing from basic data each time rather than storing intermediate results? Dr. Bie pointed out that it might be advantageous to abandon complex database management which requires thought and has considerable overheads in pointers or tables, to more simple index sequential - or even sequential - files which require much more processing but less storage and less initial intellectual development.

If the predicted wave of increased processing power really may alter the future architecture of cartography dramatically, so also may the development of new computer languages urged in the seminar by Prof. Bouillé. In comparison with SIMULA 67 or EXEL he regards FORTRAN and PL/1 as dinosaurs actively obstructing the development of a more elegant cartography. He points out that Japan is preparing a fifth generation of computers; it will include expert systems, it will allow sequential as well as parallel processing, will probably include fuzziness handling. A cartographic "machine" would in his view be a parallel processor, a non numerical processor dealing directly with the very high level concepts which we use - sometimes unknowingly - in cartography.

Another paper by another computer scientist - Dr. Neil Wiseman - points out that a national topographic database might run to 10^{11} bytes in size - greatly exceeding anything of which we have experience. Such a mass of data would be in itself such an expensive investment that it must assume longevity and must not be thrown by changes, e.g. in computers. Furthermore, such a database must anticipate constant updating as well as being structured to take account of other disciplines that impinge on topography. Is it not time, he argues, to address the architecture of such systems - starting not from our present practice of remaking ad hoc maps by substituting digitising for scribing, but by working backwards from what we can anticipate of the grand design of a national database.

There does seem much evidence - at least in Europe - to suggest that those cartographers who are involved in automation are concentrating only on remaking maps that are indistinguishable from their manual predecessors except in costing more. Perhaps it is this feeling that many of us are stuck in a rut of our own making that lies behind the statement "The evolution of map standards and conventions over the past several hundred years is almost irrelevant in approaching the future requirements for automated geospatial analysis". This is perhaps the new world of USGS redressing the balance of the old world of European cartography. My generation believed we were living adventurously in confronting the wailing wall of digitising; beyond that wall life now seems to become much more adventurous.

When conferences end, of course, most cartographers have to come down to earth and return to all the familiar problems of the map factory and its inexorable schedules. Perhaps an ecouraging first step would be a cost reduction in automated cartography of an order of magnitude - but in itself even that is not enough, we have to try and look further ahead. Many of the surveyor/cartographers who came to our seminar believed that their function was to "get the geometry right" and everything else would fall into place. Some of them left also believing that it was important to get the topology, the taxonomy and the structure right as well.

Long may the Auto-Carto-Euro-Carto link continue! I hope you will find time to browse in our proceedings when they are published and to ponder the scientific doubts and dilemmas we see ahead: these are the growing pains of the new cartography. And I hope next year you will invite Stein Bie from Oslo to tell you what has taken place at Euro-Carto II.

COMPUTER-ASSISTED MAP COMPILATION, EDITING, AND FINISHING

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ABSTRACT

Computers have been used for a number of years in the computational phases of map production at the U.S. Geological Survey. However, except for a few early isolated attempts at producing experimental editions, the computer has not been used until recently as an aid in map preparation. Historically, computer processing power was never a major issue; even the earliest computers were capable of processing data in cartographic form. The unfulfilled goal was to produce cartographic products of sufficiently high quality at cost-effective rates. Today, due to decreased costs and increased capability of specialized computer peripherals, the goal is within reach for many mapping organizations.

INTRODUCTION

For the past several years, the cartographic research program of the National Mapping Division (NMD) of the U.S. Geological Survey (USGS) has included computer-assisted cartography development activities. Paralleling these activities has been a major effort to build, utilize, and distribute a digital cartographic data base consisting primarily of information from the 7.5-minute topographic map series. Experts estimate that, when complete, this digital data base may be the largest ever constructed.

An extensive equipment modernization program resulted in the introduction of digital equipment into the NMD's four production Mapping Centers in the late 1970's. This equipment has led quite properly to the automation of various phases of the conventional mapping process (Boyko, 1982; Powell, Osick, and Miller, 1979; Troup and Powell, 1979). Each production Mapping Center is now equipped with photogrammetric digitizing equipment, graphic digitizing equipment, automatic plotters, multistation interactive editing equipment, and minicomputers.

The National Mapping Division is actively engaged in researching, compiling, and producing digital maps and data base products through the use of the Digital Cartographic Software System (DCASS). In this system, planimetric details, contours, and other map data are digitized from the stereomodel during map compilation. These data are collected without online editing capability, processed (file building/automatic error detection and correction of input errors) on a minicomputer, and then transferred to an interactive editing system for final offline editing and cartographic plotting. The initial map production work with this system has been shown to be cost effective when compared to manual methods. The system has the added advantage of providing digital data for addition to the Digital Cartographic Data Base.

SYSTEM DESCRIPTION

Digital data are collected offline during map compilation operations using Kern PG-2 stereoplotters which have been retrofitted with Altek AC 189 digitizers and Interstate voice data entry terminals. The digitizer captures and automatically records on magnetic tape the x-y movement of the stereoplotter tracing table. Automatic (stream mode) recordings are generated on the basis of the degree of line curvature. A recording circuit (essentially an electronic data reduction circuit) was developed by USGS and has been crucial for deleting extraneous data and allowing efficient computer processing of these stereomodel digital data sets. The voice data entry terminal, controlled by a Data General Nova 4 minicomputer, allows the stereoplotter operator to enter attributes without looking away from the stereomodel. The voice data entry terminal also reduces coding errors by prompting the operator to enter additional attributes for features requiring special symbology or labels.

Processing of digital data is accomplished on a Perkin-Elmer (PE) 3230 minicomputer (1.5 megabytes of core with four 300-megabyte disks) utilizing in the DCASS a collection of software developed in-house. DCASS consists of six major subsystems. Each subsystem, comprising one or more programs, exists for one primary function. The subsystem functions can be summarized as follows:

SS1 - file creation, loading, and error detection; transformation to ground coordinates and clipping to quad boundaries.

SS2 - joining of features within and between stereomodels.

SS3 - attribute editor.

SS4 - USGS digital elevation model (DEM) generation utilizing bilinear interpolation of digitized contours.

SS5 - digital line graph (DLG) generation.

SS6 - graphics generation (usually for verification purposes only).

The design of DCASS is based on the premise that interactive editing is a time-consuming task. Therefore, major error checking, identification, and correction is carried out in a batch mode during the file building stage. Approximately three-quarters of all errors are removed at this early processing stage.

The file building and batch processing stage of DCASS does not completely remove all types of input errors and was not designed for graphic enhancement; therefore, interactive editing is a necessary step in the map production flow. Interactive editing is performed on an Intergraph system which is supported by a DEC 11/70 (512K bytes of core with two 300-megabyte disks).

The DCASS digital files are reformatted and transferred to the Intergraph system for the cartographic editing and map finishing stage. USGS-developed map finishing software, called the Graphic Map Production System (GRAMPS), is used in conjunction with standard interactive edit commands to generate reproduction-quality color separation negatives. A brief description of the GRAMPS procedures follows.

As the DCASS data are read onto the disk of the Intergraph system, a complete digital map including symbology and labeling is automatically generated by GRAMPS and placed in an Intergraph design file. This automatic map generation utilizes a specifications table to allow the cartographer to specify changes without requiring computer program changes to GRAMPS. The specifications table contains the necessary feature placement information for each attribute (feature) code. Each table entry consists of four sections: the design file level to place the feature on, symbol information, label information, and special case routines. Special case routines handle features which have unusual placement requirements such as double-line road casings, area hatching, depression ticks, railroad crossties, and building symbology.

Generally speaking, interactive editing of the digital map is a two-pass process. On the first pass, digital features are edited, contours are smoothed and registered, features are added and deleted, and incorrect coding is changed. The digital map is regenerated to reflect these changes, and the nondigital edits such as repositioning of labels, symbology changes, etc., are performed on the second pass.

After interactive editing is complete, all collar and interior lettering is performed on the Intergraph system utilizing a collection of user commands and Fortran routines. Type is generated from the system font library, which contains 40 different fonts.

The generation of reproduction-quality negatives is accomplished on a Gerber 4477 plotter. The GRAMPS plotting program contains an internal sort for sorting vectors according to ascending aperture sizes. Considerable plotting time is saved by this sort because fewer aperture changes are required during the plotting. The various color separates are plotted on film either as image positives or preferably as image negatives.

After the plotting of the type and color separates is complete, the final Intergraph design file is transferred back to the DCASS data base for generation of digital products such as USGS standard digital elevation model and digital planimetric files. At this time, only the landnet and boundary planimetric data are topologically structured. It is NMD's aim to investigate the feasibility of developing additional modular software for structuring other data categories such as hydrography and transportation features.

PERFORMANCE

The preparation of Provisional edition 1:24,000-scale 7.5-minute topographic maps using stereomodel digitizing and computerized map finishing techniques shows promise to become more cost effective than conventional mapping. Provisional Mapping specifications permit departures from conventional map finishing/shaping specifications. This enables acceptance of digitally derived manuscripts with a minimum of editing. Thus, for fiscal year 1982, the stereodigital compilation rate for Provisional Maps is slightly lower than the conventional compilation rate and the computerized map finishing rate is approximately one-half the conventional rate. These digital mapping operations result in a net man-hour savings because of the almost total elimination of manual scribing (when performed to Provisional Map specifications). Some contour registration deficiencies and positional shifts in congested areas are corrected by manual scribing operations.

As with many high technology operations, startup costs (hardware, software development, procedure testing, etc.) of digital mapping are difficult to justify solely for a production operation. However, map data properly digitized, formatted, standardized, and archived in a Digital Cartographic Data Base can be used for spatial analysis in many other disciplines. Another important aspect of digital mapping is the reduced production cycle as it relates to the map finishing process. Production time for a Provisional edition of a 7.5-minute quadrangle using digital techniques from start of compilation to completion of color separates off the flatbed plotter is approximately 4 months as compared to 1 1/2 to 2 years for conventional compilation and map finishing techniques.

RESULTS

The major findings of the U.S. Geological Survey's research and development of a computer-based digital mapping system for compiling and drafting map products that meet Provisional Map specifications can be summarized as follows:

- It is feasible and cost effective to integrate digital and graphic data production operations.
- A reduction in the production time of Provisional Maps can be obtained using a computer-based mapping operation.
- Optimum filtering of the digital data can be obtained using a combination of software programs and electronic data reduction circuitry.
- Use of voice for attribute entry during the compilation phase provides increased accuracy and efficiency when compared to keyboard entry.
- Development of cartographic software systems with maximum use of automatic error detection/correction is essential to minimize the need for expensive (labor-intensive) interactive editing operations.
- Map accuracy standards can be met using digital cartographic techniques.
- There is potential for improving the system's performance through use of disk-based digitizers and improved cartographic plotters.

The transition to the digital data base mapping concept and reconfiguration of the mapping process has begun. This is one facet of the National Mapping Division's development of a National Digital Cartographic Program. The program is well underway and will accelerate during this decade.

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GIS DATABASE DESIGN CONSIDERATIONS: A DETERMINATION OF USER TRADEOFFS

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ABSTRACT

This paper describes an experiment conducted by the author to identify the kinds of tradeoffs users are willing to make concerning levels of detail and cost in utilizing a geographic database. Two case studies were developed to measure the importance of several factors: resolution, land cover classification and cost in the utilization of a land use/land cover database. Case study participants were asked to evaluate the utility of a number of hypothetical databases to solve problems presented in the case studies. In a subsequent exercise, participants were given database development prices and asked to evaluate the cost effectiveness of each database in solving the problems. Although there was a great deal of individual variation in individual ratings, there was a consensus as to the relative ranking of databases in solving case study problems. Price had a definite impact upon participant ratings of effectiveness.

INTRODUCTION

A number of states have established or are considering the establishment of geographic information systems to support natural resource planning and management. Multiagency systems have been proposed, based upon the following assumptions: 1.) a number of state agencies are engaged in similar kinds of activities and require similar analytical capabilities; 2.) many agencies require similar kinds of information and could develop cooperative databases; and 3.) the sharing of a single GIS and cooperative databases would reduce information collection, analysis, storage and retrieval expenses. The determination of user data and analytical requirements is important to the development of any information system, but the identification of the requirements for a multiagency system is complicated by the number and diversity of potential users.

IDENTIFICATION OF USER REQUIREMENTS

User involvement in the design of information systems is stressed by a number of authors (Calkins & Tomlinson 1977, Dueker 1979, Kennedy & Guinn 1976), but specific techniques and instruments to identify user requirements are rarely described. A number of of user surveys have been conducted in conjunction with the design of a GIS (Calkins & Marble 1978, Gordon 1979, Salmon et al 1977), but it has been difficult for users and system designers to evaluate potential GIS capabilities and databases through traditional interview and questionnaire techniques.

OREGON GIS REQUIREMENTS SURVEY

In 1979-1980, the author conducted a user needs survey for the state of Oregon in conjunction with a GIS design study (Brooks 1980a). Approximately 65 interviews were held, in person or by telephone, with potential users of or contributors to the proposed GIS in 13 natural resource agencies. Each program described in the interview was documented and the documentation was returned to the interviewee for review and comment. A ten page matrix of data characteristics was then developed and distributed to the interviewees to obtain additional information about data and analytical requirements. At the same time, a data inventory was conducted to identify data collections, automated or manual, which were being produced or used by the agencies included in the requirements survey.

The survey did provide useful information about the types of thematic data planners and managers require, their preferences regarding levels of detail for a number of data characteristics and their requirements for analytical capabilities. However, many of the participants were not intimately acquainted with the data they used and were not able to articulate what their requirements were or would be. This made it impossible for the project investigators to compare the results within and among departments and make judgements about the feasibility of developing shared databases, an important consideration in this design study. It was also not possible to rank the relative importance of data collections. Conversations with investigators who have conducted similar surveys have indicated that this is fairly common. Data users rarely think about the data they use in the terms a GIS designer or manager would use to determine the appropriateness of a given dataset for a GIS database (Brooks 1980b). Secondly, it is difficult for users to evaluate the utility of potential information products which they are not using at present. Finally, it is difficult for users to rate the effectiveness of potential databases or GIS products without considering development costs. GIS databases can vary considerably in terms of the level of detail at which the data are compiled and converted to machine readable form. The level of detail chosen will have a considerable impact upon system costs. Traditional interview and questionnaire techniques cannot assess the kinds of tradeoffs data users make concerning these factors.

ADAPTATION OF THE INFORMATION INTEGRATION THEORY

The problems encountered in the Oregon needs survey illustrated the need for a technique to measure the tradeoffs users would be willing to make concerning database characteristics and to identify whether or not a consensus could be achieved by diverse users about the kinds of databases which should be developed. The information integration theory was selected as the basis for a GIS design tool which would meet the above objectives. The information integration theory was developed by N. H. Anderson, an experimental psychologist, as a methodological framework for analyzing how a variety of factors are combined or integrated in the decision making process (Anderson 1970, 1974). Particular levels of each factor can be characterized by two components: a scale value and a weight. Each combination of factors is rated on a continuous scale rather than rank ordered. The relative importance of individual factors can be assessed as well as the relative desirability of various combinations of factors or options. The options are presented in a factorial design; a case study which involves consideration of three levels of three factors (3 * 3 * 3) results in 27 possible combinations. The relative importance of each factor is determined using analysis of variance techniques. Unlike other decision analysis techniques, participants do not have to articulate the importance they place on each factor out of context; factor importance is inferred from their responses. The theory was developed by Dr. Anderson to study personal decisions, but it has been adapted to study a number of other types of decisions, including consumer purchasing decisions (Levin 1976a, 1976b).

DEVELOPMENT OF THE CASE STUDIES

Two case studies were developed to measure the relative importance of two factors, resolution and land cover classification, in the utilization of a GIS database for natural resources planning. The case studies had to be general enough so that planners from a number of agencies could relate to the problems, specific enough to be realistic, and appropriate for computer analysis techniques. The first case study involved the evaluation of potential impacts of a proposed timber harvesting plan on deer and elk habitats in a 50 square mile management unit. Some background information was given about the area and participants were given a number of tasks to complete. Twelve hypothetical databases were presented and participants were asked to evaluate the utility of each on a 10 point scale in solving the problems presented in the case study. In a subsequent exercise, the participants were asked to re-evaluate the databases on a "cost effectiveness" scale and were given database development costs. A time factor was introduced at this stage, so participants actually had to consider 24 hypothetical database options.

The second case study involved an assessment of the conversion of natural resource lands (agricultural lands, range and forests) to urban uses over a ten year period. The study would eventually include the entire state, but would be conducted on a county by county basis, beginning with County Y which contained 4,500 square miles. As in the first case study, twelve hypothetical databases were presented and participants were asked to evalute the utility of each in solving the problems presented in the case study.

In both case studies, the databases differed in two respects: land classification and minimum ground resolution. In both case studies, the USGS land cover/land use classification scheme was used as the basis for the classification scheme to be used for the databases. Levels I and II were taken directly from the USGS classification scheme (Anderson 1976) since they have been standardized for the entire country. Levels III and IV were developed by the author to illustrate the differences in detail between the hierarchical levels of the classification scheme. Levels II, III and IV were considered in case study 1 and Levels I, II and III were considered for case study 2. Four levels of resolution were considered for each case study. Resolution was used rather than scale because participants in the preceeding GIS needs survey seemed more comfortable dealing with resolution. Minimum resolution levels of 160 acres, 40 acres, 10 acres and 2.5 acres were considered for case study 1 and resolution levels of 640 acres, 160 acres, 40 acres and 10 acres were considered for case study 2.

Participants in the study included Oregon resource managers and planners from the departments which participated in the GIS survey and Washington planners and managers who were involved in a similar project in the state of Washington. The level of familiarity with GIS systems varied; most participants were aware of the capabilities of such systems, although few had any practical experience with GIS or computer mapping systems. A total of 45 individuals participated in the study, 33 from Oregon and 12 from Washington. The case studies were adminstered in group sessions. Participants usually took one to two hours to complete both parts of each case study.

DEVELOPMENT OF DATABASE COST MODEL

It was necessary to develop a cost model in order to prepare the second exercise in each case study. GIS vendors were contacted to determine the average cost to digitize and edit polygons. USGS staff provided statistical information on the average number of land use/land cover polygons per square mile for urban and rural areas. The latter information was supplemented by some sampling experiments done by the author on the reduction in number of polygons when data is reclassified at a higher level (i.e., Level I as opposed to Level II). The following assumptions were made:

1. $3.50 is the average cost of digitizing and editing a polygon;
2. For the most detailed level of classification (i.e., Level IV):
   a. 640 acre resolution = 1 polygon/sq. mile
   b. 160 acre resolution = 4 polygon/sq mile
   c. 40 acre resolution = 8 polygon/sq mile
   d. 10 acre resolution = 12 polygon/sq mile
   e. 2.5 acre resolution = 16 polygon/sq mile

3. Reducing the level of classification detail by moving up the hierarchy would reduce the number of polygons/square mile by the following factors:
   a. Level IV = 1
   b. Level III = .8
   c. Level II = .64
   d. Level I = .625

These assumptions were reviewed by several vendors and GIS users. The purpose of this model was not to predict the cost of a particular database, but to indicate the relative differences in cost at different levels of detail. The database options included in each case study are listed in Table 1.

TABLE 1

CASE STUDY DATABASE OPTIONS

CASE STUDY 1 Resolution/Class	Price	CASE STUDY 2 Resolution/Class	Price
160 acres/II	$ [illegible]	640 acres/I	$ 7875
160 acres/III	$ 560	640 acres/II	$ 10080
160 acres/IV	$ 700	640 acres/III	$ 12600
40 acres/II	$ 896	160 acres/I	$ 31500
40 acres/III	$1120	160 acres/II	$ 40320
40 acres/IV	$1400	160 acres/III	$ 50400
10 acres/II	$1345	40 acres/I	$ 63000
10 acres/III	$1680	40 acres/II	$80640
10 acres/IV	$2100	40 acres/III	$100800
2.5 acres/II	$1790	10 acres/I	$ 94500
2.5 acres/III	$2240	10 acres/II	$120960
2.5 acres/IV	$2800	10 acres/III	$151200

DATA ANALYSIS TECHNIQUES

Although the information integration theory is usually analyzed using ANOVA techniques, several other statistical tests were used for this application. We were interested in the degree of consensus as well as individual responses. If participants reached no agreement as to the ranking of the various options, this technique would not be very useful as a GIS design tool. The Kendall W Coefficient of Concordance (Siegel 1956) was used to identify the degree of association among the participants' rankings of the options. This is an appropriate test because it measures relative rankings rather than absolute ratings. Therefore, even if respondent A is a high scorer on a point scale and respondent B is a low scorer, the Kendall W Coefficient will still express the relationship between their ranking of options. The W score is not linear and its significance is tested by an associated chi square value. SPSS ANOVA was used to statistically determine the significance of the factors and their interactions in producing the ratings. Regressions were also run to identify other factors which might have influenced the variability in responses.

ANALYSIS OF RESULTS

There was a considerable amount of variability in individual responses as illustrated in Figure 1.

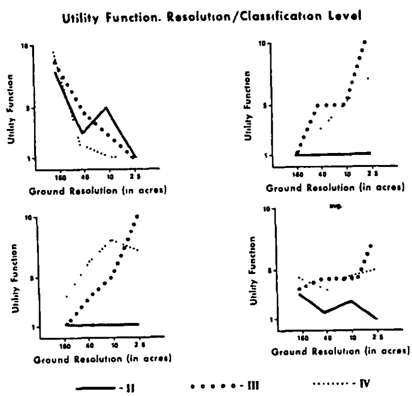

FIGURE 1

The rankings for utility and cost effectiveness for Case Study I are given in Table 2. As can be expected, the most detailed information was considered the most useful while the least detailed was considered the least useful. When cost was included as a factor in the cost effectiveness exercise, the order shifted slightly. This is to be expected since the most detailed databases are also the most expensive.

TABLE 2

CASE STUDY 1 - RANKING OF DATABASE OPTIONS

Utility	Cost Effectiveness
2.5 acres/IV	10 acres/IV
10 acres/IV	10 acres/III
2.5 acres/III	2.5 acres/IV
10 acres/III	40 acres/IV
40 acres/IV	40 acres/III
40 acres/III	2.5 acres/III
10 acres/II	40 acres/II
160 acres/IV	10 acres/II
2.5 acres/II	2.5 acres/II
160 acres/III	160 acres/III
40 acres/II	160 acres/IV
160 acres/II	160 acres/II

The interaction between resolution and classification was significant as measured by an ANOVA F score. In the information integration designs upon which this experiment was modeled, investigators were able to identify the relative weights of each factor in the assignment of ratings. However, this is not a meaningful statistic when the data is not linear. The stepwise regression indicated that classification may have a greater bearing on the scores than resolution, but there is a great deal of variability which is not accounted for by these factors. This individual variability is due to several factors:

1. individual differences in the application of a point scale
2. differences in the perception of the problem and its solution
3. different pricing thresholds.

There was considerably more variability in the second exercise in which price was introduced. Although the dollar range was not great for this case study, prices varied from $700 to $2800, price did have a dampening effect on the ratings and on the relative rankings of responses illustrated in Figure 7. The interviews in the GIS needs study and discussions generated during the case study sessions clearly indicated that planners and managers are not used to separating out data costs. They were very sensitive about the potential costs of a GIS, even though it is quite likely that their current data costs are high but hidden.

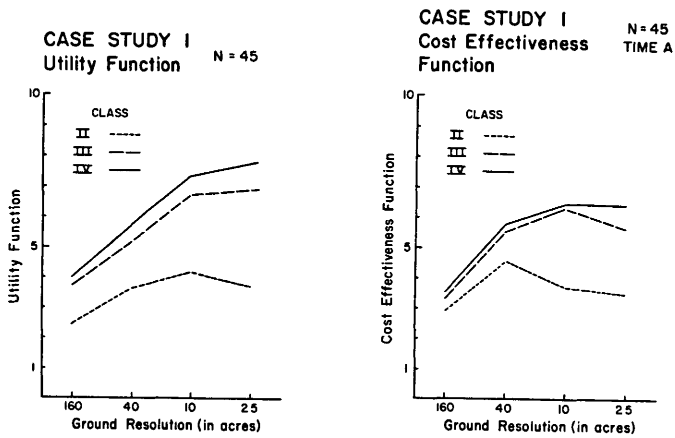

FIGURE 2

There was less agreement about the utility and cost effectiveness of database options in case study 2, although the Kendall W scores were still significant. Participants expressed greater difficulty in dealing with the case study and were more ambivalent about the data requirements. Again, as shown in Table 3 there were interactions between classification and resolution in the utility exercise, and resolution produced a higher R value in the regression analysis.

TABLE [illegible]

CASE STUDY 2 - RANKING OF DATABASE OPTIONS

Utility	Cost Effectiveness
40 acres/II	40 acres/II
10 acres/II	160 acres/II
10 acres/III	160 acres/I
40 acres/III	40 acres/I
40 acres/I	40 acres/III
160 acres/II	160 acres/III
160 acres/I	10 acres/II
10 acres/I	640 acres/II
640 acres/II	640 acres/I
160 acres/III	640 acres/III
640 acres/I	10 acres/I
640 acres/III	10 acres/III

The most significant aspect of these results are the differences in the relative rankings of database options in the utility and cost effectiveness exercises, illustrated in Figure 3. In fact, several of the most highly rated options in the utility exercise were ranked very lowly in the cost effectiveness exercise. Some participants simply could not deal with the higher prices. One of the original case studies in the pretest dealt with a statewide problem, but the cost figures were so high that the pretest participants recommended that the study be scaled down.

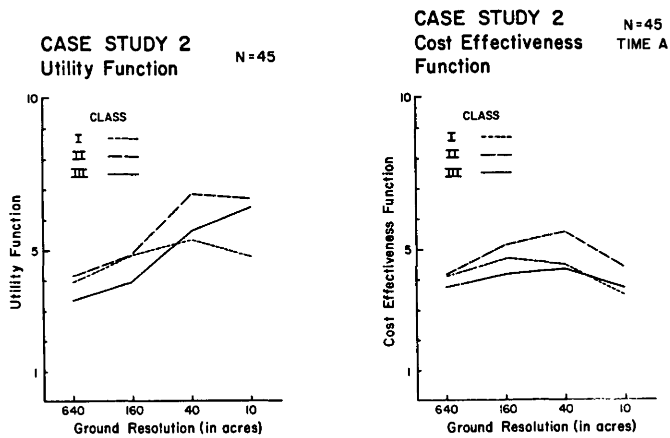

FIGURE 3

CONCLUSIONS AND RECOMMENDATIONS

The specific results of these case studies may not be generalizable beyond several superficial observations:

1. cost has an impact upon user perception of the value of information.
2. there is a great deal of variability in the evaluation of data even among colleagues with similar backgrounds and responsibilities

The exercise was a useful one as an educational experience for the users. The sessions generated a great deal of discussion about data requirements and forced participants to think about data they use and their relationship to the tasks they perform. The case studies provided a common framework for participants from different departments to discuss the differences in their requirements, i.e. the foresters and wildlife biologists. Such an exercise may also serve as a method of generating consensus or, at least determining whether or not consensus can be reached. A followup Delphi session is planned in which participants will be given their scores and group scores and asked to submit a new set of ratings.

I would make several recommendations concerning the use of this case study factorial approach. Database options were presented in a random fashion, so as not to bias participants into setting up an empirical rule to rate factors.

Some participants actually set up a matrix on paper to develop such a rule while others attempted to do so mentally. The exercises would have taken less time if options had been presented in a matrix and it would have allowed participants to be more consistant in their application of whatever rules they chose to follow. Participants were not allowed to look at their utility ratings when they did the cost effectiveness ratings. More consistant results would have been achieved if this had been allowed. Even though it is rather time consuming to develop realistic case studies, it is far less expensive than conducting bench mark tests or demonstration projects. This approach cannot take the place of such exercises, but case studies can provide provide GIS designers information about user requirements and tradeoffs, resolving some of the problems in user needs assessment.

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A THEORY OF CARTOGRAPHIC ERROR AND ITS MEASUREMENT IN DIGITAL DATA BASES

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ABSTRACT

The processes of map production are necessarily approximate, and thus the resulting map contains a variety of error effects. This paper develops a theory of information content that applies to geometric details on a map, based on the epsilon distance model. Examining map production technology, the epsilon model provides a reasonable approximation of the error expected. This error can be measured, and an example is worked using data from the GIRAS digital files produced by USGS. Under conservative assumptions, 7 percent of the selected study area around Pittsburgh lies in zones of potential error.

INTRODUCTION

A model of map error based on a deductive approach can be derived from consideration of the objects measured and the processes that placed these objects on the map. By studying the sequential processes of map production and analysis, a model of error has much more coherence than the empirical results from a few specific maps. This paper concentrates maps of nominal scale data, such as land use or soils. These maps consist of polygons created by a network of lines, and the areas of these polygons are frequently calculated. These areas are then used with very little regard for their potential inaccuracies.

This study concentrates on the variability which is inherent in the map production process. For the sake of simplicity, divergence between the map and the earth's surface is termed "error". This word may be a bit harsh, but it should not imply that the map is "wrong", just that the map is limited.

INFORMATION MODELS

A fundamental model of spatial structure is captured by the topological approach to cartographic data structures (Corbett, 1975). However, topological relationships limit themselves to basic set theory and the abstract ramifications of dimensionality. The basic topological model does not consider the geometric detail of the map, so it is inadequate to model the variability of that detail.

Recursive Bands

One information model has been advanced by Thomas Poiker (formerly spelled Peucker, 1975) as a theory of the cartographic line. The theory derives from research initially developed for the removal of detail in cartographic representation (Douglas and Peucker, 1973).

Given a cartographic line represented as a set of straight line segments, the argument hinges on a definition of information content. Poiker suggests that the correct basis for using a more complex representation should be the measurement of deviation from a trend line. If a point is selected, two new trend lines are defined and the process is applied recursively. During the procedure a series of trend lines and deviations are calculated; these measurements define rectangles with one axis along the trend line, the sides displaced from the trend by the deviation.

Epsilon Distance

As a model of variability for a line, the recursive banding approach has disadvantages. In particular, the bounding rectangles often contain wide areas far from the line, while the inflection points are directly on the edge. A model of variability might start with another definition of the information content of a cartographic line, based on the theory of epsilon distance (Perkal, 1956; 1966). This theory is no more "correct" than Poiker's; it merely offers a better opportunity for this particular application.

Given a cartographic line as a straight line approximation, it might be supposed that the true line lies within a constant tolerance, epsilon, of the measured line. For a straight line segment this locus is simple, consisting of the union of a rectangle parallel to the segment, twice epsilon wide, with circles of radius epsilon centered at each end point. By union of this simple figure, more complex lines can be handled. The band can also be described as the area occupied by rolling a ball along the line.

SOURCES OF ERROR

A map is produced by a specific progression of procedures which accept, process and transmit information in various forms. The amount of error contributed depends on the technical details of each step, so error analysis cannot be fixed for all maps. Blumenstock (1953) pioneered the deductive approach to overall variability resulting from the accumulation of errors in each step. His analysis covered sampling temperature and generating an isarithmic map. Here a similar approach will be taken for cartographic features such as lines which bound land use zones.

This section will review some of the more recurrent forms of cartographic error. It does not cover all conceivable error sources, nor does it probe in detail the sources mentioned. The goal is to demonstrate the applicability of the epsilon model to a representative range of the problems contributing to actual error.

Locating Ground Position

Measurement of the earth's surface is an age-old science which has attained remarkable sophistication. Current high performance in geodesy, surveying and photogrammetry results from continual efforts, often spread over hundreds of years or more, to perfect these disciplines. It is interesting to note that these disciplines devote substantial concern to the mathematical study of error, providing ever higher standards of performance. However, the promise of technical perfection does not mean that it is attained. Any map is a fossil, reflecting the technology used in its production. Due to the lags of production, it is very difficult to keep any map coverage (from national topography to municipal cadastre) uniformly updated to the best current technology. In addition, organizations without specialized cartographic expertise (such as planning agencies) may not have access to the latest techniques and equipment.

Errors in locating ground position can be minimized by spending more money, but it would be foolish to increase accuracy in this phase of map production without regard for the rest of the process. It is little use to eradicate centimeter errors with laser survey equipment, only to introduce meters of imprecision with inexact linework and unstable paper (see below).

The error in surveying and geodesy applies to the points measured and, by extension, to all information interpolated between the known points. For simple point objects, a point error model is adequate, but most maps consist of more complex features. The epsilon model provides a method to apportion the uncertainty in surveying to all features on the map.

Interpretation

Studies of error in locating ground position are typically concerned with "well defined" points (Thompson, 1960), but the bulk of cartographic detail does not consist of distinct points. Most maps consist of lines which might represent entities directly, as in the case of railroads or faults, or the lines might serve as boundaries of areal units. A boundary line represents a change from one areal feature to another. The spatial accuracy of the line is dependent on more than the technology of surveying, because the line has to be perceived in the first place. Locating a line involves discrimination of the adjacent features; the difficulty of doing this depends on the particular case. Property boundaries have a very precise meaning and usually can be located quite exactly, but the border between forest types might not be a line at all, just a fuzzy zone of interpenetration and transition.

Discrimination at borders is only one possible source of interpretation error. For instance, a completely erroneous classification could be recorded. However, such an error is not really a spatial problem. Standard misclassification analysis, used in medical diagnosis and other fields (Fleiss, 1973), provides useful tools to deal with such errors. These methods differ from the deductive approach of this paper, because they rely on some form of resurvey, although the findings of the two approaches can be integrated.

Scale

Scale is more than the mathematical relationship between the earth and the map; scale implies a specific decision about generalization and aggregation. Error in procedures such as surveying are adjusted according to the scale of output required. Scale has a similar impact on interpretation. MacDougall (1975) attributes most error to lack of "purity", but strict classification accuracy is inevitably sacrificed to scale. For example, standard practice in land use mapping lumps scattered corner stores into residential neighborhoods (Anderson and others, 1976).

In spite of the recognition of scale in most systems of classification, it is normal to assess accuracy by point sampling (Fitzpatrick-Lins, 1978). Differences in the land use detected by this procedure might be misleading. Scale-specific effects might require that a point be swallowed up in a larger zone, or the sampling point could lie near an imprecise boundary. It would be difficult to disentangle these error effects to allow sampling at different scales.

Conversion to Map Space

Projections are only a small issue in transfering measurements onto maps, although they receive generous attention in cartography. In general terms, drawing a map involves two physical objects, "pen" and "paper", controlled by a person. These three components introduce their own forms of error.

Perhaps the simplest effect is created by the "pen". Whatever writing implement might be used (pencil, scribing tool, or ink pen), a line is represented by a narrow region of more or less constant width. With the highest state of the art, line widths will be quite uniform and as narrow as .1 mm, but many maps use much wider lines. The mark made by a pen, incidentally, provides a near perfect rendition of the epsilon model with epsilon set at one half the pen width.

The error effects of drafting are not confined to the physical nature of the pen. A human operator wields the pen and attempts to record spatial information. The decisions made will generate error, depending on the nature of the information available and the technology used. A common problem, though not the only one, is registration where visual clues are used to align two images. When misregistration is less than the line width there is no easily detected visual clue. However, when the error is larger, it produces a sliver zone. The outside edge of the traced line may be up to one and one half line widths away from the center of the source line before any sliver appears.

The problem of line following and misregistration will appear in any manual phase in the production process. Degradation of map accuracy caused by graphic revisions such as retracing has been documented in a number of cases (Libault, 1961, p. 68; Harley, 1975, p. 165). Modern digital production should remove redrafting from the production flow, but it will not remove the errors already introduced in existing map series.

Traditionally, maps reside on paper. This material is cheap, flexible and durable, but it is also dimensionally unstable. Humidity can change spatial measures substantially and often permanently. A one percent change in length is demonstrated to be possible (Libault, 1961; Braund, 1980). In evaluating the whole map production process, errors of this magnitude can dominate all other effects. Although high quality map production now requires stable base material, paper maps are an unavoidable legacy of the historical record. Any data source on paper should be treated very cautiously.

Digital Handling

Production methods have evolved from the traditional hand methods to considerable reliance on computer processing of cartographic information. Automation will reduce error in so far as it avoids redrafting and similar degradation of the information. Digital systems have an aura of accuracy, but they do have inherent error effects which cannot be avoided.

The simplest problem is that computers use finite precision for storage and calculations. The effects of roundoff introduce a uniform distribution around the coordinates stored. If the points are reasonably close, these zones merge to approximate the epsilon model. Rounding also introduces some possibility for error in calculations, but this requires careful analysis of the specific program.

The largest potential errors in digital map processing occur during digitizing, whether performed by manual devices or by automated scanning. In both cases, hardware characteristics will introduce some amount of error. Manufacturers often quote the resolution of the device (the smallest measurement produced), creating the impression that this describes its accuracy (the expected error of measurements). However, a .001 inch resolution is usually coupled with .005 inch "repeatability". Other errors can arise from the width of the spot on the cursor of a manual device.

Manual digitizing resembles drafting, so similar errors should be expected. The lack of direct visual feedback may degrade digitizer results compared to drafting. Some tentative results on the magnitude of digitizer error were obtained in an experiment by Thorpe (1981, personal communication). He measured the deviation between a known set of contours and the results of manual and laser line follower digitization. The laser device was able to keep virtually all of its measurements in a band two line widths across; the average deviation was about a third of the line width. The manual operator was five times less accurate. Additional, carefully designed studies of digitizer error are needed to establish the reliability of digital data.

Combining Effects

Each error effect relevant for a particular map can be treated as a random variable, perturbing the true line to obtain the observed line. A crucial part of this analysis hinges on combining these separate error effects. Each error effect tends to occur as the spatial information is passed from phase to phase in the sequential process of map production. For example, any surveying error is incorporated in the data at that stage and is then treated as correct. This situation suggests that the processes can be treated as independent. In this case, sufficient results are obtained by adding the variances of the distributions (Blumenstock, 1953; Chrisman, 1982). This is a result of the calculus of probability functions, known in surveying as the Law of Propagation of Errors. An epsilon band as wide as the average deviation has the property that deviations outside are exactly balanced by those inside. Thus the area of the band is a reasonable measure of the uncertainty of area measurement.

MEASURING EPSILON BANDS

The epsilon model of map error remains a theoretical curiosity without a practical method of measurement. The epsilon band consists of all points within a distance epsilon from a line. As demonstrated above, this locus forms a band around an isolated line. However, this definition ignores one of the most important features of most maps; the lines are connected, not isolated. The error model is designed to estimate the amount of area subject to fluctuations, and no area should be counted twice.

Perimeter is an imprecise estimator of the epsilon band, but it is closely related, and adequate for very small epsilon. The most obvious modification of perimeter measurement is at the angle formed by each adjacent pair of lines. A circular section occurs on the convex side of the angle, where perimeter would undercount, while a pair of triangles on the concave side represent overcount. The triangles are bound to be larger than the circles, and hence the net effect is to subtract from the perimeter value. Since both the circles and triangles increase with epsilon squared, while perimeter effects only increase linearly with epsilon, the net effect is increasingly important with larger epsilons.

It is possible to detect other cases along a line where bands interact and overcounting occurs. Cases which are sufficiently common should be incorporated into routine epsilon measurement. Of course, a local approach, by definition, does not try to examine all possibilities. However, the simple case dominates in normal circumstances [Chrisman (1982) measured other effects and showed that they were trivial].

AN EXAMPLE OF EPSILON ERROR MEASUREMENT

In order to provide a concrete test case, the epsilon measurement program was applied to data obtained from the GIRAS digital files - the U.S. Geological Survey's Land Use/Land Cover series (Mitchell and others, 1977). Of six test cases performed (Chrisman, 1982), a single example is presented here. A rectangle of approximately 100,000 hectares around the city of Pittsburgh was extracted from the Pittsburgh sheet.

Setting Epsilon Width

Examination of the map production processes used by the Geological Survey yielded three error effects that could be quantified (Loelkes, 1977). The line width amounts to 25 meters on the ground. Thus, line width drafting error might have an average deviation of 12.5 meters under the very best circumstances. Digitizing was performed by the same hardware tested by Thorpe, giving another deviation of 8.3 meters. Roundoff contributed 2.9 meters average deviation. These error effects combine to an average deviation of 15.2 meters using the formula for adding random variables discussed above. It was decided that an epsilon band of 20 meters would be quite conservative, considering that interpretation error was not estimated and effects such as registration could not be judged.

Measurement Results

The total area measured in the epsilon bands of 20 meters amounts to 7191 hectares, or about 7 percent of the total. Higher figures are obtained in more complex areas; in other rectangles studied total error reached 10.9 percent of total map area (see Chrisman, 1982). Overall these figures come within the 85 percent classification accuracy goals stated by USGS, but the error model only accounts for boundary errors, not gross classification error.

Table 1 (see separate page) contains the results provided by the measurement program applied to the Pittsburgh area. The categories of the rows and columns are the Level II land use codes defined by the U.S.G.S. (Anderson and others, 1976). In each cell of the matrix the top figure is in hectares, while the lower figure is a row percentage. The rows of this square matrix represent the land use as mapped; the sum of the row is the total area on the map. The columns represent the same land use categories, but as possible recepients of error effects. The diagonal contains the 93 percent of the map which is not affected by the epsilon bands.

Bounds on Area Measurement

In many fields, such as engineering or physics, measurements are usually presented with the best estimate "plus or minus" one standard deviation. This allows an open statement of reliability that should be provided with any scientific measurement.

The figures in Table 1 provide the raw material for placing bounds on area measurements. For a given category, the sum of its row (disregarding the diagonal) is the amount it might lose, while the column sum is the amount it might gain. These two figures provide separate "plus" and "minus" estimates, which are slightly different due to shape effects. The asymmetry of the error bands provides valuable information reflecting the spatial structure of the map. The separate bounds could be stated separately (e.g. 41 : 34284 hectares + 1977 - 2016), but I think that would be confusing. A more readable presentation uses the sign "<" (less than) to present a lower bound and an upper bound on either side of the measured area: lower bound < area < upper bound (see Table 2). These bounds should be

Table 1: Cross-tabulation of error measurements (Pittsburgh rectangle)

by Anderson code, each cell: area in hectares on top, row percent on bottom, diagonal:no error

	11	12	13	14	15	16	17	21	41	42	43	51	53	74	75	76
11	37230	210	197	80	5	13	203	117	1041	27	91	64	7	0	58	30
	94.6	0.5	0.5	0.2	0.0	0.0	0.5	0.3	2.6	0.1	0.2	0.2	0.0	0.0	0.1	0.1
12	196	2167	23	14	1	1	18	12	65	-	-	9	-	-	8	2
	7.8	86.1	0.9	0.5	0.1	0.0	0.7	0.5	2.6			0.4			0.3	0.1
13	192	23	2599	21	-	4	5	6	68	-	5	131	-	-	9	6
	6.3	0.8	84.6	0.7		0.1	0.2	0.2	2.2		0.2	4.3			0.3	0.2
14	77	14	21	1105	4	-	6	10	97	-	3	14	-	-	13	-
	5.6	1.0	1.5	81.0	0.3		0.4	0.7	7.1		0.2	1.0			1.0	
15	5	1	-	4	154	-	-	-	2	-	-	2	-	-	3	2
	2.8	0.8		2.3	88.6				1.2			1.2			1.9	1.2
16	13	1	4	-	-	191	-	2	14	-	1	-	-	-	-	-
	5.6	0.3	1.7			84.6		1.0	6.3		0.5					
17	192	18	5	6	-	-	2355	14	78	1	3	2	-	-	5	2
	7.2	0.7	0.2	0.2			87.8	0.5	2.9	0.0	0.1	0.1			0.2	0.1
21	120	12	7	10	-	2	15	8432	363	-	30	-	-	-	34	3
	1.3	0.1	0.1	0.1		0.0	0.2	93.4	4.0		0.3				0.4	0.0
41	1054	70	71	98	2	15	82	368	32268	-	-	68	4	-	136	51
	3.1	0.2	0.2	0.3	0.0	0.0	0.2	1.1	94.1			0.2	0.0		0.4	0.1
42	27	-	-	-	-	-	1	-	-	390	-	-	-	-	-	-
	6.5						0.3			93.3						
43	92	-	5	3	-	1	3	31	-	-	2432	6	-	3	18	-
	3.6		0.2	0.1		0.0	0.1	1.2			93.7	0.2		0.1	0.7	
51	64	9	132	14	2	-	2	-	67	-	6	1898	-	2	3	1
	2.9	0.4	6.0	0.6	0.1		0.1		3.1		0.3	86.3		0.1	0.2	0.0
53	6	-	-	-	-	-	-	-	3	-	-	-	30	-	-	1
	14.5								8.5				75.7			1.3
74	0	-	-	-	-	-	-	-	-	-	3	2	-	41	-	-
	0.4										7.3	3.9		88.3		
75	57	9	10	13	3	-	5	32	128	-	16	3	-	-	1824	1
	2.7	0.4	0.5	0.6	0.2		0.3	1.5	6.1		0.8	0.2			86.8	0.1
76	28	2	6	-	2	-	2	3	48	-	-	1	1	-	1	531
	4.5	0.4	1.0		0.3		0.3	0.5	7.7			0.2	0.1		0.2	84.9

interpreted as standard deviations, not absolute limits.

Table 2: Probable bounds on area measurements

11	37230	<	39374.1	<	41498
12	2167	<	2516.0	<	2885
13	2599	<	3070.9	<	3552
14	1105	<	1363.7	<	1626
15	154	<	174.2	<	194
16	191	<	226.2	<	262
17	2355	<	2681.9	<	3024
21	8432	<	9028.2	<	9622
41	32268	<	34284.7	<	36261
42	390	<	418.4	<	447
43	2432	<	2594.6	<	2753
51	1898	<	2199.0	<	2500
53	30	<	40.1	<	51
74	41	<	46.2	<	52
75	1824	<	2101.7	<	2391
76	531	<	625.8	<	724

The figures in Table 2 provide a summary of Table 1 while losing some of the structure of spatial interdependence. Area estimates derived from fallible sources, such as maps, should be presented with bounds such as these so that a user does not take a measurement too literally.

CONCLUSIONS

The epsilon model of information content suits the purposes of understanding the variability of cartographic lines. By deduction, the uncertainties introduced in the steps of cartographic production can be estimated. This paper set forth a simple triginometric procedure to measure the area of the epsilon bands. The resulting error estimates provide a more realistic description of area measurements obtained from maps. This paper presented the theory and practicalities of error measurement, but there is a need for further inductive studies to calibrate the model. In addition, this work should lead to new statistical procedures for treating spatial information which are sensitive to the structure of spatial interdependence described by the error procedures.

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PICDMS: A GENERAL-PURPOSE GEOGRAPHIC MODELING SYSTEM

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ABSTRACT

The Picture Database Management System (PICDMS) is a new system developed and implemented at the University of California, Los Angeles. It performs a wide range of data processing functions on sets of two-dimensional variables, as requested in a simple user language. The data base can be a set of pictures, images, or functions including, for example, digitized Landsat satellite photographs, an array of elevation measurements, and census tract boundaries for the same area, together with data derived for the region from tables or other sources. Possible operations include definition of new pictures such as vegetation maps based on elevation values and ground truth tables as well as the set of photographs; modification of existing images according to arbitrary criteria; calculation of the minimum distance from a geographic point to a specified census tract; deletion of an image; listing of sets of values derived from the image data base; computation of numeric information; or printing of maps showing correlations among the existing variables. New data can be added without affecting old user programs. The user gives the minimum information needed by the system for completely flexible operation; the system finds the rest of the information it needs in a data dictionary. The user specifies the type of operation (add, replace, or delete an image, compute a distance or some arbitrary numeric function, list values or print a picture). He defines the format of any new data, specifies the part of the region to be operated on in terms of values of the existing variables, and describes the effect on a set of variables of surrounding values of other variables. Simple operations can be defined in one- or two-line English-like sentences; arbitrarily complicated ones can also be defined in a straightforward manner. The system analyzes the user command in terms of the existing data base and the relative amount of computer memory available, and builds a simple computer program to perform the operation. A future Operations Dictionary will allow still easier definition of standard procedures.

INTRODUCTION

The Picture Database Management System PICDMS is a novel approach to two-dimensional data processing: an easy-to-use general-purpose computer system that allows a non-programmer to define simple or complicated operations over a surface such as the Earth, a medical image, or a silicon chip. Many

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sets of data may belong to each surface, for example satellite photographs, maps, census tracts, etc. The user may perform standard and nonstandard operations on arbitrary subsets of this data, modifying or augmenting operations and data as he wishes.

This system was originally developed for applications in cartography and geographic modeling. Automated mapmaking is an example: registration of new aerial photographs to an old map, interpretation and abstraction of them to display new information, and overlay on the original map, all within a few hours. PICDMS allows experimentation with different output formats; different colors, symbols, and projections can be tried at little extra cost (as recommended by Morrison et al., 1975). Special-purpose maps can be produced from a general set of data in order to present a single theme clearly: data that is not immediately relevant is eliminated or downplayed. Such maps are often of too-limited interest to justify the expense of manual production. The same system can be used for very detailed, quantitative analysis of resources by comparing photographs to known ground truth information, as is done in Landsat multispectral grid cell classification. In addition, PICDMS can model geologic or geographic processes over a region using multiple types of data and providing snapshots at desired intervals. Manual computations for such two-dimensional models are necessarily very simple, both because of the large number of calculations and the time consumed in drawing maps. PICDMS permits more modeling steps, more experimentation, and more detailed and more complex models. Other possible uses of this software include brush fire modeling (Chock, 1982), and placement of health care facilities (Chock and Klinger, 1982).

DYNAMIC STACKED-IMAGE DATA STRUCTURE

The PICDMS dynamic stacked-image data structure is a set of images (which may be photographs, diagrams, or two-dimensional variables), registered to the same coordinate grid, with values for a single grid cell stored in a logical data record. The format of this record varies as images are added to or removed from the data base. The cellular rather than vector data structure provides superior representation of the subtle variations in photographs, and versatility in data manipulation. A variation on the "stacked image" concept proposed independently by Albert L. Zobrist (Zobrist, 1977) and by Robert M. Haralick (Haralick, 1977) is used: all images are registered to the same projection or camera location and scale, and a rectangular grid is then superimposed on them.

In order to allow interrelation of data from various sources, all data for a cell is stored in a single conventional data record (Figure 1). This format also allows a choice of data types for image values -- integers, floating-point numbers of various lengths, or character strings. The simple, sequential, uniform-format files can be used by virtually any computer system.

In other systems this structure is sometimes too rigid,

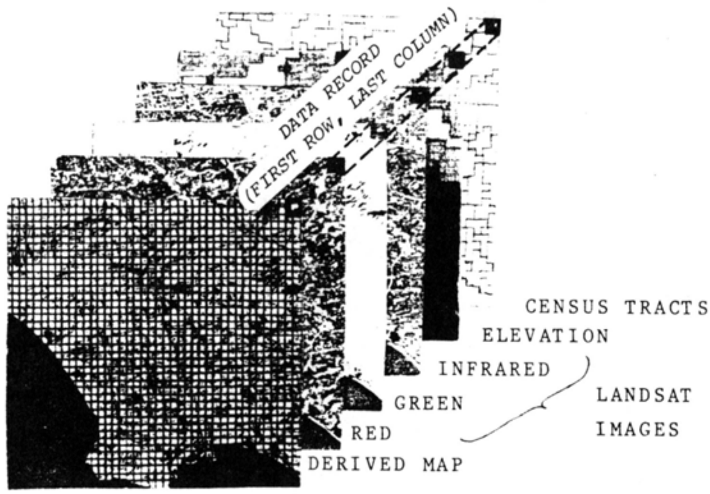

Figure 1. A Stacked Image Data Base. Each (row, column) record contains one data item per image: in this example, intensities for Landsat red, green, and infrared spectra, elevation, and pointers to census tracts.

requiring predefinition of the data: file management is simplified at the cost of storage wasted in unused blank fields; new attributes are required to conform in name, type, and length to the predefined fields; and system expansion is limited by the number of spare fields available for new data.

In PICDMS on the other hand the record structure is made variable: a new image is added as a new field in each data record, well-integrated with the existing data. A Data Dictionary keeps track of the current record format and job control language parameters needed by the system, by methods invisible to the users. There is no storage space wasted on blank images. The system can use a variety of image coding formats, and there are no limits on addition of new information to the data base.

A PICDMS data base consists of sets of these image stacks, each with its own area of coverage and scale. Each user sees his own private stack, to which new data he defines is automatically added, and which he can modify. He may also be able to read information from other stacks, but can not change them.

WINDOWED SCAN DATA MANIPULATION

The data manipulation facilities of PICDMS were built with two goals: a) to support any geographic data processing operation that could reasonably be performed on gridded data, and b) to make such operations as simple and standard as possible for the user without imposition of arbitrary restrictions on them. The first goal was set by collecting published data manipulation capabilities of a variety of automated geographic and cartographic systems (Table 1). This list is by no means exhaustive (some of

	KANDI DATS	IBIS	SYMAP	BASIS	IMAID	AGS	ODYS-SEY	POL-YVRT	NIMS	STAN DARD	WRIS	CGIS	GEO-QUEL	GADS
OPERATIONS ON IMAGES														
EDGE OPERATORS	G													
CLUSTERING	G													
COVARIANCE	G													
AVERAGE GRID CELL VALUES	G	G												
POINT CLASSIFICATION	G	G												
HISTOGRAMS OF GRID CELL VALUES	G	G	G											
THRESHOLDING	G	G			G									
TEMPLATE MATCHING					G									
OPERATIONS ON SCATTERED POINTS														
INTERPOLATION			G											
THEISSEN POLYGONS			G											
CONTOURS	G		G			P	P							
PROJECTION CHANGE	G	G				P	P	P						
OPERATIONS ON LINES														
NEAREST POINT ON A LINE					P									
CENTER OF A LINE					P									
GENERALIZATION							P	P						
INTERSECTION OF NAMED LINES					P		P							
POINT-TO LINE DISTANCES					P				P					
LINE LENGTHS					P				P	P	P			
OPERATIONS ON REGIONS														
POLYGON OVERLAY (INTERSECTION)	G	G	G	G	P		P		P		P	P	P	
CROSSTABULATION OF OVERLAYS		G							P					
FIND ADJACENT POLYGONS							P	P						
AGGREGATION								P			P	P		P
POINT IN POLYGON					P				P	P				
AREA					P					P	P	P		
CENTROID					P							P	P	
OPERATIONS ON REGION ATTRIBUTES														
RELATIONAL OPERATIONS					P								P	P

*P represents data in polygon format G represents data in gridded format

Table 1. Some data manipulation capabilities of cartographic and geographic systems (Chock, Klinger, and Cardenas, 1981)

these systems are known to have extensive libraries of programs), but it indicates some of the major capabilities useful in a cartographic system, and also the way the systems tend to specialize.

The PICDMS basic data access algorithm can be varied to support any of the data manipulation operations in Table 1, and many others besides. This algorithm runs a small window (Figure 2) over all designated regions covered by the image stack. Each cell in these regions has its turn as the "active" cell: relevant data from the cells surrounding it are read and manipulated, and the results modify the active cell, or add new information to it, or contribute to a set of calculations, or are listed or displayed in a picture.

The PICDMS Data Manipulation Language describes all necessary variations on the basic algorithm. It is a set of logic and arithmetic statements about values of any set of images as seen through the window, and specification of the use to which this information is to be put. Programs for the operations in Table 1 were written or sketched in this language. Some version of any of these operation types could be performed by at most two fairly simple commands.

The user specifies the type of operation (add, replace, or delete an image, compute a distance or some arbitrary numeric function, list values or print a picture). He

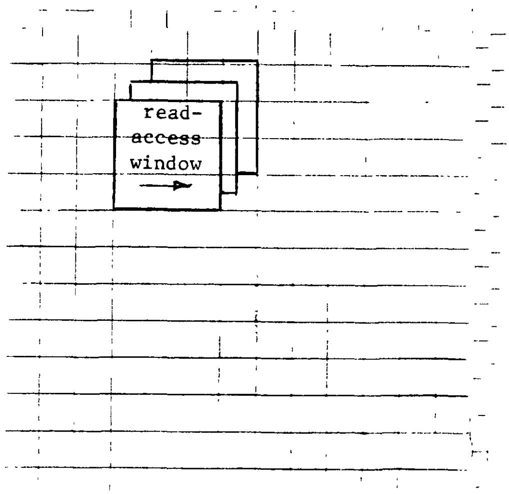

Figure 2: Windowed scan access to an image stack.

defines the format of any new data, specifies the part of the region to be operated on in terms of values in the existing images and describes the effect on a set of variables of surrounding values in a set of images. Simple operations can be defined in one- or two-line somewhat English-like sentences; arbitrarily complicated ones can also be defined in a straightforward manner.

The Data Manipulation Language will eventually support a family of simpler, more specialized languages for specific applications, with commands that can be defined and redefined for specific user groups.

EXAMPLES

The PICDMS Data Manipulation Language is perhaps best described by a set of examples.

Example 1

A vegetation map is derived from elevation measurements, ground truth tables, and aerial or satellite photographs:

```
ADD (VEGET IMAGE CHAR)
     VEGET = 0,
     IF BAND4 > 22 AND BAND4 <= 24 AND ELEV < 2000
          THEN VEGET =  'A',
     IF BAND4 > 24 AND BAND4 <= 30 AND ELEV < 2000
          THEN VEGET =  'B',
     IF BAND4 > 30 AND BAND5 <= 24 AND BAND5 > 18
          AND ELEV < 2000
               THEN VEGET =  'C',
     IF BAND4 > 30 AND BAND5 <= 30 AND BAND5 > 24
          AND ELEV < 2000
               THEN VEGET =  'D',
     FOR ELEV > 0;
```

Here a new vegetation map image called 'VEGET' is added to a stack which already contains spectral band 4 and band 5 photographs and an array of elevation measurements interpolated to the same pixel (resolution cell) locations. Vegetation type 'A' is known to reflect light at intensities between 22 and 24 at the band 4 wavelength, but only grows below 2000 feet of elevation. Other types are mapped according to similar sets of criteria. The symbol '0' is the default value if no vegetation type is defined for elevations above sea level; for lower elevations, the system leaves the map blank.

Example 2
The minimum distance from Los Angeles City Hall to Census Tract 900 is found:

```
DISTANCE FOR
    (LANDMARK = 'CITY HALL') AND (CITY = 'LOS ANGELES'),
    (CENSUS = 900);
```

The data base is scanned until a cell is found that fulfills one of the two conditions: there is a city hall in the 'landmark' image in a cell corresponding to the Los Angeles part of the image mapping cities; or the cell is in the '900' section of the Census Tract image. The scan continues until a cell is found satisfying the other condition. PICDMS calculates the distance between the two cells. The scan continues from the row and column where the second condition was first fulfilled. As more Tract 900 cells are found, their distances from the City Hall cell are calculated, and the minimum of these distances is printed.

Example 3
A set of values is listed:

```
LIST BAND6, BAND7 FOR VEGET = 'B';
```

The spectral band 6 and 7 light intensities are printed out for each cell with vegetation type B.

Example 4
The vegetation map image is discarded:

```
DELETE VEGET;
```

Example 5
The minimum elevation of Los Angeles County is found:

```
COMPUTE (V1 FLOAT), IF BEGINNING THEN V1 = 10000,
    V1 = MIN(V1, ELEVATION), FOR COUNTY = 'LOS ANGELES';
```

A floating-point number is initialized at a value known to be greater than the minimum elevation. During the raster scan, V1 is compared to the elevation of each cell in Los Angeles County, and the minimum value found is kept. After the scan, the minimum elevation value found is printed.

Example 6
The vegetation map of Example 1 is displayed rather than added to the data base:

```
PRINT, SYMBOL = 0,
    IF BAND4 > 22 AND BAND4 <= 24 AND ELEV < 2000
        THEN SYMBOL =  'A',
    IF BAND4 > 24 AND BAND4 <= 30 AND ELEV < 2000
        THEN SYMBOL =  'B',
    IF BAND4 > 30 AND BAND5 <= 24 AND BAND5 > 18
        AND ELEV < 2000
            THEN SYMBOL =  'C',
    IF BAND4 > 30 AND BAND5 <= 30 AND BAND5 > 24
        AND ELEV < 2000
            THEN SYMBOL =  'D',
    FOR ELEV > 0;
```

Example 7
PICDMS is unusual in its ability to operate in two-dimensional space on multiple variables, as in this version of the standard Roberts cross-operator for edge detection. The first PICDMS command below measures the band 7 spectral values from a Landsat image and creates an image ROBERTS, showing 'edges' where the gray level changes sharply.

```
ADD (ROBERTS IMAGE FIXED(10))
    ROBERTS = ABS(BAND7(I,J) - BAND7(I+1,J+1))
        + ABS(BAND7(I,J+1) - BAND7(I+1,J)),
    IF ROBERTS > 128 THEN ROBERTS = 1,
    ELSE ROBERTS = 0,
    FOR BAND7 NOT = BLANK;
```

The image added to the data base is called ROBERTS; it has ten-digit integer values. Each cell (I,J) of ROBERTS is assigned a value based on the value of BAND7 at (I,J) and at three neighboring cells. The operation is performed on all cells of BAND7 for which data is defined: undefined cells such as imaginary ones outside the image stack or those not assigned data values are described by the system code BLANK. The system will assign last row and column of ROBERTS the value BLANK, since values can't be computed by the given formula. If the resulting image shows too little detail in low-lying areas, the user might augment the command:

```
ADD (IMAGE ROBERTS FIXED(10))
    ROBERTS = ABS(BAND7(I,J) - BAND7(I+1,J+1))
        + ABS(BAND7(I,J+1) - BAND7(I+1,J)),
    IF (ELEVATION > 2000) AND (ROBERTS > 128)
        THEN ROBERTS = 1,
    ELSE (IF ELEVATION<= 2000) AND (ROBERTS > 64)
        THEN ROBERTS = 1,
    ELSE ROBERTS = 0,
    FOR BAND7 NOT = BLANK;
```

PICDMS SYSTEM CONFIGURATION

PICDMS uses a translator-processor system configuration to convert the current data base format and the user's immediate goals to an efficient computer process. The Translator (Figure 3) reads the user's command to determine the operation the user wants to perform, and on which data. It then reads the Data Dictionary to locate the required images and set up the input and output formats. It chooses an access method based on the operation, the quantity of data

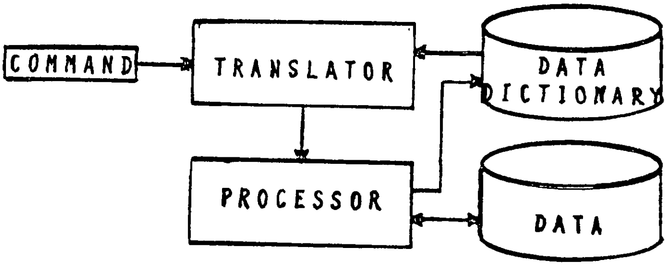

Figure 3. Translator-Processor Configuration

involved, and the amount of computer memory available.

There are currently three access methods; simple sequential raster scan of the image stack, whole-stack processing (if all stacks needed can fit in memory at once), and multirow (which allows efficient scan of each row of each stack for more limited memory, if raster scanning is inadequate for the operation). More direct access methods are also being developed, which again will be under system control. The Translator generates a Processor, a program which integrates all this information and does the actual work on the data base.

CONCLUSION

The current operational version of PICDMS is an end-user oriented, general-purpose processor of two-dimensional (particularly geographic and cartographic) data. It is being developed by addition of still simpler, more specialized languages, by increased capabilities (including interfaces to vector or line segment data, permanent storage of tables, and simultaneous use of data at different scales), and by adaptation to smaller computers and specialized processors (graphics devices, parallel processors). PICDMS is both a powerful, flexible tool for difficult data processing applications and a novel approach to data structure and access.

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Scottish Rural Land Use Information System Project

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ABSTRACT

This paper provides a description of an important effort in land use data processing in Great Britain. The organization, motivation and technology used in a pilot project are presented and discussed. The results of the research are also presented along with information on how the data can be acquired by interested researchers. The paper does not go into great detail but rather presents a snapshot of the multi-faceted project in order to bring it to the attention of others working in this field.

INTRODUCTION

The prime mover of the Rural Land Use Information System project (RLUIS) was the Scottish Development Department (SDD), an agency charged with the responsibility of overseeing all strategic land use planning in Scotland. The SDD had chaired a standing committee to deal with the particular question of rural land use planning for a number of years. In 1978 it requested the assistance of a consultant from the University of Edinburgh to advise on how the committee could improve the day to day handling of the vast amount of data collected by each of the participating agencies.

The consultant reported to a special working party in March of 1979 and in addition to providing the committee with a thorough description of existing data processing methods, the report also made many suggestions for improving existing practices with particular emphasis given to the need for automation and computerization since few of the agencies were making use of such practices.

The working party acted on this advice and proposed a pilot project to investigate the feasibility and cost of creating a shared data processing system which could provide both statistical and map output. The major problem was, as usual, the funding. It would be limited to approximately $100,000 and would only be available for one year. With these restrictions in mind the working party set out to put a project together that would not be over ambitious but at the same time meaningful.The membership of the working party was as follows:

Scottish Development Department (SDD)
Countryside Commission Scotland (CCS)
Department of Agriculture & Fisheries Scotland (DAFS)
Forestry Commission (FC)
Institute for Geological Sciences (IGS)

Macauly Institute for Soil Research (MISR)
Nature Conservancy Council (NCC)

The first requirement of the working party was to try and use it's scarce time and funds as practically as possible. For that reason it looked to existing facilities and organizations rather than attempting to create something entirely new. The earlier consultant's report had pointed out a recreation planning system which was funded by national agencies and which provided both map and statistical output from a well maintained recreational data base. The Planning Data Management System (PDMS) was contacted and it's sponsors agreed to join the working party in an attempt to broaden it's scope to deal with the wider range of land use data.

The existing PDMS facility did not provide a digital mapping component, only a grid square oriented, line printer produced map. For that reason it was decided that GIMMS Ltd., a company with a computer mapping package which produced more traditional line drawn maps on a plotter, was invited to tender for carrying out improvements to it's software and linkages to the existing software used by PDMS. All work was carried out in the Department of Geography at the University of Edinburgh where PDMS was housed.

The third major contractor to be involved was the Ordnance Survey (OS), the national mapping agency. The OS was involved in the automation of their map production facilities and were just beginning to look at the possibility of broadening their role to provide not only maps but digital data bases to customers. They agreed to participate in the project and to make available their existing data for the study area.

SCOPE AND OBJECTIVES

The scope of the project was limited by the scarcity of time and money. The first step was to choose a study area. The districts of Dunfermline and Kirkaldy in the Fife Region of Scotland were chosen. The land area was only 1/100th of the 79,000 Sq. Km. of Scotland the area was rural and it was under pressure from oil related development and urbanization. The planners in Fife Region welcomed the opportunity to participate in the project and made their data available to the working party.

In addition to deciding on the feasibility and cost of creating a rural land use system for Scotland the working party also had particular requirements which it wanted to have met. The system would have to be able to deal with both the whole of the country but also in detail with particular areas of pressure and development. In particular the participating agencies were interested in the question of the urban-rural fringe and the problems caused by increasing urbanization.

Finally, the working party hoped to achieve an improvement in the way that the participating agencies shared existing data. This would be the necessary first step to take no matter what technology would evolve from the project.

THE DATA

The participating agencies covered a vast spectrum of land use activities and this was reflected in the data that they collected and injected into the project. It is also true that the PDMS had created and maintained a large data base and this was also at the disposal of the working party. It is not possible to give details of all the data used in the project but the following table identifies the statistical data used in the project.

It should be noted that a very valuable set of data was contributed by Fife Region, the local planning authority. In Britain all proposed development to land and property is controlled by the local planning authority and details of such development are solicited before any approval is given or refused. Fife had point referenced the centroid of each property or land parcel effected by development proposals. The referencing system was the OS national grid and was to an accuracy of 100 meters. This data provided the true measure of actual and potential pressure on the ground and was a vital element when integrated with the more strategic data collected by the national agencies.

Boundary data was submitted to the OS by the participating agencies for digitizing. Before describing this process more fully it should also be noted that the OS also provided data from their own map production data base including the following features:

- Coastline
- Limit of Sand Mud and Shingle
- Lakes
- Rivers, Streams, Drainage Channels
- Administrative Boundaries
- Main Road Network
- Main Rail Network
- Electricity Transmission Lines
- Footpaths
- Pipelines
- Parks

Unlike the statistical data, which only had to be coded and punched into the computer, the digital or boundary data was a costly element of the system. Most agencies updated maps by hand to reference boundaries of interest to them. The scales and methods of annotating differed from one agency to another. For the purposes of the project it was decided that a common scale would be used (1:50,000) and that agencies would prepare base maps as digitizing documents for use by the OS. Guidelines were provided by the OS and GIMMS Ltd. whose GIMMS mapping package would be used to process the data. Even the OS had to reorganize it's data with reference labels to enable the software to create polygons. The OS in map production work did not become involved in this activity.

This aspect of data collection and validation was by far the

TABLE I

ACQUISITION OF STATISTICAL DATASETS

NO.	DATASET	DATA HOLDING AGENCY	ORIGINAL COLLECTING AGENCY	DATE RECEIVED
DATASETS IN TRIP DATABANK				
11	LANDFORM	PDMS	PDMS	Held by PDMS
15	BEACHES	PDMS	CCS	Held by PDMS
29	NATIONAL TRUST SITES	PDMS	PDMS	Held by PDMS
27	RECREATIONAL FACILITIES	PDMS	TRRU	Held by PDMS
41	POPULATION	PDMS	OPCS	Available to PDMS
48	CCS GRANT - AIDED SITES	PDMS	CCS	Held by PDMS
DATASETS COLLECTED BY RLUIS AGENCIES PRIOR TO PROJECT				
6	GEOLOGICAL BOREHOLES	IGS	IGS	? . 2. 79
23	DERELICT SITES	SDD	SDD	24 . 2. 79
39a.	PROPERTY BY POSTCODE	FIFE	FIFE	4 . 5. 79
44	PLANNING APPLICATIONS	FIFE	FIFE	28 . 6. 79
50	AGRICULTURAL CENSUS BY HOLDING	DAFS	DAFS	27 . 9. 79
46	PLANNING APPEALS	SDD	SDD	5 .10. 79
45	PLANNING REFERRALS	SDD	SDD	5 .10. 79

DATASETS HELD BY RLUIS AGENCIES AND COLLECTED BY OTHER RLUIS AGENCIES PRIOR TO PROJECT				
32	MAJOR INDUSTRIAL SITES	SDD	FIFE	? . 3. 79
47	HOUSING LAND AVAILABILITY	SDD	FIFE	11 . 4. 79
49	RESIDENTIAL LAND PRICES	SDD	FIFE	19 . 6. 79
DATASETS HELD BY RLUIS AGENCIES AND COLLECTED BY NON-RLUIS AGENCIES OR DEPARTMENTS PRIOR TO PROJECT				
30	ANCIENT MONUMENTS	SDD	NATIONAL MONUMENTS BOARD	18 . 5. 79
42a.	EMPLOYMENT STATISTICS	FIFE	DEPT. EMPLOYMENT	3 .10. 79
43	UNEMPLOYMENT STATISTICS	FIFE	DEPT. EMPLOYMENT	3 .10. 79
17	SCOTTISH WILDLIFE TRUST SITES	NCC	SWT	10 .10. 79
DATASETS HELD AND COLLECTED BY NON-RLUIS AGENCIES PRIOR TO PROJECT				
52	TRAFFIC FLOW FIGURES	SDD (ROADS)	SDD (ROADS)	6 . 7. 79
54	CLIMATE	MET. OFFICE	MET. OFFICE	12 . 7. 79
53	WATER SUPPLY FIGURES	SDD (WATER)	SDD (WATER)	24 . 9. 79
53a.	SEWAGE TREATMENT WORKS	SDD (WATER)	SDD (WATER)	24 . 9. 79
21	AREAS OF ABANDONED MINING	NCB	NCB	-
22	AREAS OF INFILL AND SUBSIDENCE	NCB	NCB	-
DATASETS COLLECTED SPECIFICALLY FOR PROJECT				
13	LANDUSE 1 KM.	PDMS	PDMS	26 . 3. 79
14	LANDUSE 100 M.	PDMS	PDMS	16 . 8. 79
16	HABITAT	NCC	NCC	22 . 8. 79

most costly element in the project.

THE SOFTWARE

The PDMS software (TRIP) produced statistical output similar in nature to that produced by SPSS or SAS. It also produced grid square (5km or 1km) maps on a line printer. These maps were seen as a valuable tool by the working party in as much as they allowed for an overview or snapshot of the whole of Scotland at the 5 km level or of a whole district or region at a 1 km level. The mapping was functional because all data in the data bank was point referenced to 100 meters or data was collected by grid square. The working party felt that this was a good starting point but that they would require further detail and greater resolution in their mapping needs. They looked at the GIMMS mapping system and felt that it had the basic requirements and that it could be improved to provide the necessary analytical tools they required.

GIMMS Ltd., in response to the requirements of the working party, made substantial improvements to the GIMMS mapping package. Firstly, it provided an OS interface which allowed the software to be used to read the OS data base provided to the project. The topological checking facilities of the software were also improved to reduce the time required to check and validate the digitized data provided by the OS.

The major addition to the software was the adding of spatial search routines that would allow for the location and manipulation of points, lines and polygons in relation to each other by way of distance or data characteristic. This search capability was seen as vital by working party members along with GIMMS capability to provide flexibility of scale when producing map output. The only problem encountered was the need to provide a polygon overlaying technique. This proved impossible within the funding and time limits. However, GIMMS did provide a capability to convert polygonal data to grid data for area comparisons and to provide a link to the TRIP mapping system.

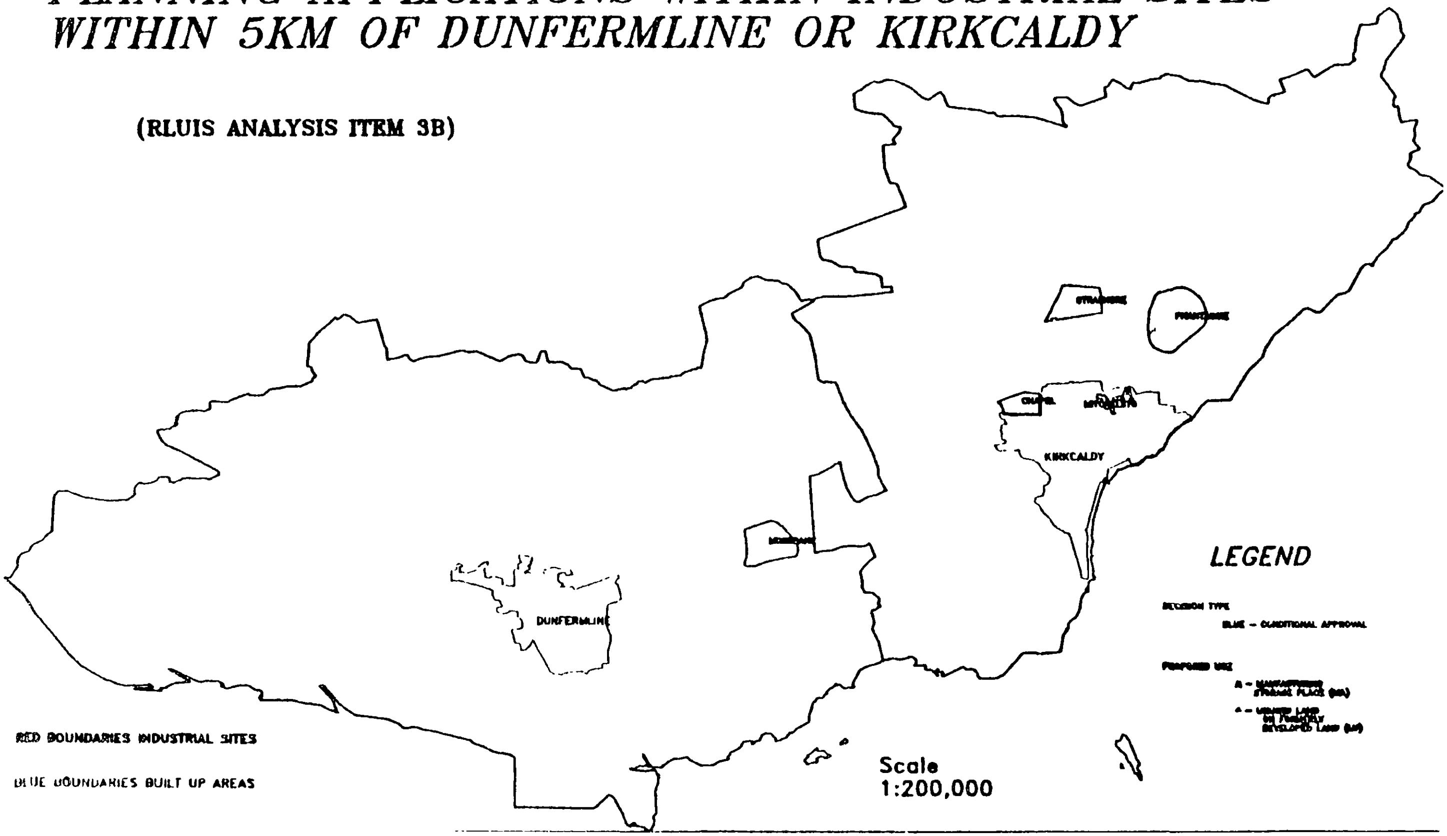
One other feature that should be noted is that of generalization. The GIMMS software included a generalization routine which would reduce the number of co-ordinates in a boundary at the time of file creation. The detail provided by the OS was often greater than was required for the analytical exercises undertaken. The employment of generalization often cut the cost of analyses and maps by as much as 50%.

THE ANALYSIS

The time restraint meant that only a limited number of analyses could be specified by each of the participating agencies. In addition to the more routine statistical analysis produced by TRIP the participants requested both grid square and digital map output. Primarily the requests were of a sieve mapping nature. That is to say that they required a sifting of the data base to meet a number of requirements which could be related to the presence or absence of a particular data characteristic and/or the

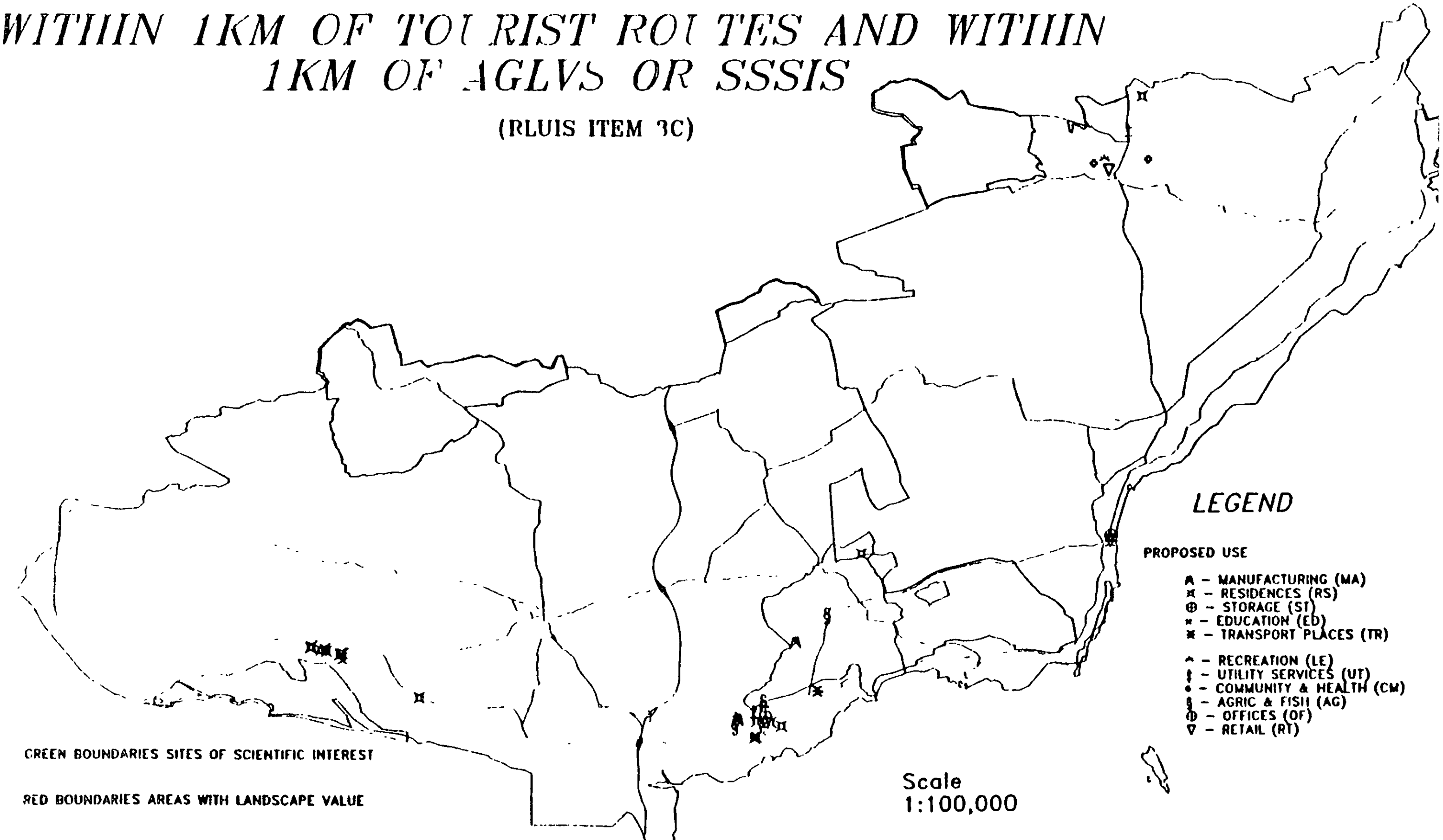
PLANNING APPLICATIONS WITHIN INDUSTRIAL SITES WITHIN 5KM OF DUNFERMLINE OR KIRKCALDY

(RLUIS ANALYSIS ITEM 3B)



WITHIN 1KM OF TOURIST ROUTES AND WITHIN 1KM OF AGLVS OR SSSIS

(RLUIS ITEM 3C)



GREEN BOUNDARIES SITES OF SCIENTIFIC INTEREST

RED BOUNDARIES AREAS WITH LANDSCAPE VALUE relationship of data or areas to each other in distance. The following maps provide some example of the type of question that were being asked and the results that were produced.

CONCLUSIONS

The project concluded in August of 1980 with reports from the major contractors and a final report from the working party to the Standing Committee. The analyses were 90% complete within the time scale with only some of the larger digital data sets not processed within that time. The conclusions were that the concept was a good one, the need was great, and that the basis of a rural land use system for Scotland was created. Feasibility was not the question, cost was. The tremendous expense of digitizing the data for the study area was seen as a major road block to extending the system to all of Scotland. Indeed, the costs would not be 100 times greater but were estimated as possibly 1000 times greater given the nature of the data for the rest of the country. The OS used manual digitizing techniques and are still looking at the feasibility of automatic techniques which, if employed, could reduce costs significantly.

The question of scale also required further study since the 1:50,000 scale did not satisfy some agencies with more specific needs for high resolution. The concept of a scale free data base was seen as the objective but again the cost factor was a problem.

Another conclusion was that many agencies needed to improve the way that they collected and annotated data. More coordination would be required prior to data collection to facilitate a greater utilization of the data at the analysis stage. The sensitive nature of some of the data also presented organizational problems. Further thought would have to be given to the operation of such a system. Would it be a central facility or a distributed one? Could it be located in a university or commercial environment or would it have to be run by central government? These questions all required further study.

THE AFTERMATH

Today no further development of the system has taken place. The participating agencies still use the university facilities for further analysis of the existing data or to add to their holdings. The reason for no further action is purely financial as government spending cuts have prohibited further research.

The OS has undergone a review and their role has not been expanded to provided digital data bases to customers. Once again this is a result of the lack of funds to support such an effort. The OS has continued to evaluate other automated techniques for increasing the efficiency and economy of their digitizing effort.

GIMMS Ltd. has incorporated all the improvements inspired by the project into release four of the GIMMS system which it sells throughout the world. Indeed many of the individual agencies have acquired the GIMMS software to use within their own facilities to carry out analysis and map production.

In conclusion it must be said that the pilot project did achieve a great deal. The achievements were probably greater in the administrative and education aspects than in the technical dimension. That is to say that individuals and agencies who participated finished with a greater appreciation of the capabilities of an automated system as well as an awareness of the fundamental need to have a sound administrative and managerial foundation to establish and maintain data collection, classification, and coding standards. The project provided the opportunity for the many agencies to work in a more coordinated fashion and they did not waste the chance. This will provide many improvements in land use planning in Scotland for many years to come.

Finally, the report to the working party and the contractor's reports as well as the data base are available to any researcher or research organization. To obtain a copy write to:

Mr. Eric Goodwin
Scottish Development Department
New St. Andrew's House
Edinburgh, Scotland U.K.

SPATIAL OPERATORS FOR SELECTED DATA STRUCTURES

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ABSTRACT

The discipline of mathematics is characterized by a small, fundamental set of operators which, when taken in concert, support complex manipulations and analyses. In a similar sense, higher levels of spatial applications programming are founded upon a fundamental set of spatial operators. The tendency to focus upon geometric elements and operators based upon the dimensionality of space is perhaps due to the straightforward manipulations of these elements on a conceptual level. Given the necessity for continuous geometric elements to conform to a discrete, sequential computer storage, our purview should be extended to a primal level that exploits the discrete qualities of spatial data representations.

INTRODUCTION

The U.S. Geological Survey (USGS) is currently compiling a Digital Cartographic Data Base (DCDB) consisting of digital elevation models, digital line graphs, and thematic data. Contained in the data base will be numerous categories of information relating to transportation features, hydrology, public land net, administrative boundaries, and land use and land cover. The potential size of the data base is extremely large; with complete coverage of the conterminous United States requiring several trillion bits of spatial data.

To complement its role as a generator of digital map data, there is an increasing realization of the need for the USGS to develop and expand capabilities for supporting applications programming. Although applications programming, per se, may be as varied as the individual contexts of the users, a fair degree of underlying commonality does exist among applications. The concept of spatial operators is thus an appealing one. Spatial operators, analogous to mathematical operators, perform fundamental manipulations on spatial data and can be used in combination to support more sophisticated types of analyses.

Spatial operators have been keyed to the dimensionality of space. The basic manipulations of point entities, linear entities, and areal entities, which are defined to be operators, are straightforward on a conceptual level. Implementation considerations, however, must address the representations of these conceptual spatial elements as afforded by alternative spatial data structures. Herein lies the proverbial problem of spatial data handling; that is, "of managing a two-dimensional continuous view of reality in a natural and efficient way within the discrete and sequential computer storage" (Tamminen, 1980).

An approach is outlined below that explicitly extends the purview of spatial operators to primal spatial elements. A taxonomy is envisioned for the formulation of spatial operators ranging from a user-logic level of abstraction to a primal level. Primal elements are based upon components for the discrete representation of geometric entities. Primal operators are formulated about a minimal structure. They perform basic manipulations independent of higher order constructs and thus are suitable for alternative data structures.

SYNTAX AND TERMINOLOGY

An operation, as given in mathematics, is a process or action performed in a specified sequence and in accordance with specific rules of procedure. That which distinguishes an operator from an operation is the straightforward and fundamental nature of the action, such that an operator is typically referenced by a commonly accepted symbol or abbreviation.

The syntax is simple. Operators act upon operands to produce a result. Operands, in turn, are defined by the values that they may assume and the type of operators to which they may be subjected. Given operands of a certain type and an appropriate operator, the results generated are of an expected form.

In higher level programming languages, the constructs of operators and operands are handled explicitly. A variable is declared to be of a particular data type (e.g., LOGICAL, REAL, INTEGER, etc.). This variable, in turn, constitutes a valid operand for an operator which is defined to act upon its data type.

A case has been made for a spatial data type (Aldred, 1974), but the data types, and respective operators, inherent to programming languages are found not well suited for spatial data handling. Candidates for spatial data types typically reference the dimensionality of space; that is, nodes (point entities), arcs (linear entities), and polygons (areal entities). (Dimensions greater than two are not considered in this discussion for simplicity.) Existing mathematical operators such as addition, multiplication, exponentiation, and the like have little meaning for spatial entitities. Conversely, operations including logical polygon intersection, union, and difference are very relevant to spatial data handling but cannot be expressed by existing operators.

What constitutes a spatial operator may lie in the eyes of the invoker; however, some frequently referenced spatial operators are listed in Table 1. A spatial operator is classified as monadic or dyadic depending upon whether it acts upon a single or a pair of geometric operands. Dyadic operators are further classified as symmetric or asymmetric. Symmetric operators are commutative; the order of the operands is not significant. With asymmetric operators, the order is important. Results of spatial operators are categorized as numeric, boolean, geometric, or a particular type of geometric entity.

Table 1. Commonly referenced spatial operators

N: node, A: arc, P: polygon, G: geometric (i.e., N,A,P), Nu: numeric, B: boolean, Mon: monadic, Dya: dyadic, Sym: symmetric, Asy: asymmetric.

Operator	Class	Operand	Result	Comments
Length	Mon	A	Nu	
Area	Mon	P	Nu	
Boundary	Mon	P	A	
Box	Mon	G	P	Bounding rectangle.
Extend	Mon	G,Nu	P	Search areas about N,A or P.
Union	Dya,Sym	G	G	
Intersection	Dya,Sym	G	G	
Difference	Dya,Asy	G	G	
Separation	Dya,Sym	G	Nu	Shortest distance.
Equality	Dya,Sym	G	B	
Inequality	Dya,Sym	G	B	
Contain	Dya,Asy	G	B	
Share	Dya,Sym	G	B	

A spatial operator can be defined in a manner sufficiently concise and sufficiently general by adopting a recursive definition:

A spatial operator is:

(a) A straightforward manipulation of a spatial entity with the result in an expected form; or
(b) A sequential set of spatial operators; or
(c) An iterative application of a spatial operator.

The issue arises as to the definition of a spatial entity. Definitions based upon the dimensionality of space appear only to address the issue from one perspective, that of an object geometry. To a user, whose applications are to be supported by spatial operators, individual polygons, arcs, and nodes are but abstractions of the user's view of spatial reality. Spatial entities, and respective operators, may be defined for a user-logic level.

Moreover, polygons, arcs, and nodes represent entities in a continuous two-dimensional space, and they, in turn, may be abstracted to conform to the discrete nature of computer storage. The digital representations of geometric entities are comprised of lower level spatial entities that are referred to here as primal spatial elements.

These multiple perspectives suggest an approach where spatial operators are formulated about entities at different levels--a user-logic level, a geometric level, and a primal level.

USER-LOGIC LEVEL

The purpose of spatial operators is to provide for the structured manipulation of spatial entities, which, in turn, supports some higher level, user-specific application. At a user level of abstraction, entities such as nodes, arcs, and polygons are not likely to have much meaning. Rather, spatial reality from the user's view is comprised of point features, linear features, and areal features, each with their respective attributes. These geographic features comprise spatial entities at the user-logic level.

Spatial operators may be formulated about entities at the user-logic level which need not access the object geometry. Instead, references to spatial entities are limited to an indexing system as it would be for an aspatial type of observation. The following are examples modeled after simple query types given by Martin (1975):

Ai(Ej)	$=$	??	What is the value of attribute i for spatial entity j?
	$>$		
	$<$		
Ai(??)	$=$	Vk	What spatial entities have values for
	$\neq$		attribute i that are equal to (etc.) a value k?
	$>$		
	$<$		
??(Ej)	$=$	Vk	What attributes of spatial entity j
	$\neq$		have values equal to (etc.) a value k?
??(Ej)	$=$	??	What are the values for all attributes of spatial entity j?
Ai(??)	$=$	??	What are the values of attribute i for all spatial entities?
	$>$		
	$<$		
??(??)	$=$	Vk	What are the attributes of all
	$\neq$		spatial entities that have a value equal to (etc.) a value k?

These simple operators can be used in combination to formulate more complex operators. For example, the set intersection of all spatial entities with an attribute 'i' less that a value 'k' AND an attribute 'r' greater than a value 's'. The limitations of indexing-type operators, however, become apparent when user queries address spatial characteristics and locational aspects of the entities. To accommodate fundamental types of explicitly spatial queries, operators are formulated about a geometric level.

GEOMETRIC LEVEL

Associated with entities in the user's frame of reference is an object geometry; that is, the nodes, arcs, and polygons that relate to spatial features in the user logic. It is the object geometry that must be accessed to handle explicitly spatial queries. For example, an indexing structure cannot handle, say, 'the area within a distance 'd' of some linear feature'.

A one-to-one mapping is not likely between entities at the geometric level and entities at the user-logic level. The State of Michigan is typically given as an example of a single user-logic entity (State jurisdiction) corresponding to two geometric entities (the upper and lower peninsulas). Various hierarchial and lattice pointer structures can be established to track the topological relationships between the user-logic and geometric levels.

Complexities in formulating spatial operators at the geometric level focus upon two factors--the distinction between objects of dimensionality, and the lack of distinction between continuous spatial entities and their respective representations within the discrete and sequential computer storage.

Consider the node, arc, and polygon typology in the context of the intersection of two polygons. It is not difficult to conceive of a resulting configuration that yields not only common subareas of the polygons, but also common arc segments and common nodes. This result does not conform to the predefined categories of the typology.

A suggested approach (Cox and others, 1980) would define a 'geometric' data type that would accommodate mixed configurations of nodes, arcs, and polygons. It is not resolved as to whether the geometric data type would constitute a single data type or coexist with node, arc, and polygon data types. In the latter case, a new operator, 'dimensional select,' can be defined to extract a node, arc, or polygon data type, and ignore extraneous data.

Consider again the intersection of two polygons. On a conceptual level where polygons can be viewed as continuous, two-dimensional elements, their intersection is easily identified. Similarly, given representations that allow for the definition of continuous spatial elements, the intersection is easily specified. For example, the circular regions about two points, (x_1,y_1) and (x_2,y_2), with radii of r_1 and r_2 respectively can be expressed in equation form. The intersection of the two areas is the set of points (X,Y) such that:

$$[(X-x_1)^2 + (Y-y_1)^2 \leq r_1{}^2] \text{ .AND.}$$

$$[(X-x_2)^2 + (Y-y_2)^2 \leq r_2{}^2]$$

An .OR. condition would indicate the union of the two areas.

Only the most regular of spatial entities are easily defined by mathematical equations. Given the irregularity characteristic of spatial entities, a coordinate representation must be employed that conforms to the discrete computer storage.

The conceptual elegance of spatial operators at the geometric level is quickly lost at implementation time when the once continuous elements are treated in a discrete manner. A straightforward algorithm for polygon intersection based upon a vector representation is feasible only for the simplest of configurations. The number of required comparisons between vectors approach a near-exponential growth. Referencing available topological relations and invoking sorting routines reduces the permutations, but the sense of a straightforward, basic manipulation is lost.

In contrast, Merrill (1973) has demonstrated the elegance of raster implementations for polygon overlay. Rasters, however, do not represent a complete solution given the loss of definition for the logical spatial elements.

Burton suggests that a spatial operator not be tied to any particular data representation (Burton, 1979). Instead, a spatial operator could be invoked for the representation that best suits it. The circular polygon that results from extending a node, for example, can be represented by the equation of the circle. Implicit in this spatial operator/data representation independence are the capabilities for the effective conversion among different representations and the intelligence for determining their applications.

Perhaps some of the complexities described above can be alleviated by transplanting manipulations of the discrete elements which are used to approximate continuous spatial entities from the geometric level to a subordinate level. Operators at the geometric level may focus upon the manipulation of geometric entities as continuous elements. For example, given a circular polygon represented in equation form, geometric operators can be defined to return polygon area, boundary, perimeter, extreme coordinates, and the like without referencing a discrete representation of the polygon. The same polygon in raster or vector form can be passed to a subordinate, primal level for action by respective primal operators.

In addition, operators at the geometric level can be formulated about relations between geometric entities that do not require direct consideration of the respective image data. For example, an operator that, given a polygon, returns adjacent polygons.

Capabilities for converting from one representation to another, for invoking efficiency steps such as sorting and the like, and for identifying relevant elements of a geometric configuration (e.g., dimensional select), would form an interface between the geometric and primal levels.

PRIMAL LEVEL

The key underpinning of the primal level is that constructs are basic and structure is minimal. Perhaps by adhering to this requirement, a set of primal operators, together with primal data types, can be defined which will serve various applications regardless of higher level data structures.

A primal level is defined about the most fundamental construct of spatial data--a point, any higher order constructs (e.g., arcs, polygons) are reducible to relationships among points. And the manner in which continuous spatial entities are treated in discrete, machine-compatible form can be exploited to define primal spatial elements (Figure 1).

NODE SEGMENT: A point which is distinct, or unrelated to adjacent points, or related to itself.

VECTOR SEGMENT: A set of points, delineated by two end points, that are related along a single dimension in two dimensions.

HALF-PLANE SEGMENT: A set of points, delineated by two end points, that in part define the limit of a set of points related in two dimensions.

RASTER SEGMENT: A set of points, delineated by two end points, that in part define the extent of a set of points related in two dimensions.

Each of the primal elements is based upon a set of points that may be delineated by two points (a null relation for node segments). This allows for a uniform logical record format for the primal elements that can simply be expressed as [ET PT1 PT2], where ET is an element type code, and PT1 and PT2 are the coordinate pairs of the two endpoints.

For nodes, PT1 and PT2 are identical. For half-plane segments, the order of the endpoints can be defined such that related points are always to the right (or left) of the segment. A similar rule may be useful for raster segments; the first entry being the leftmost point. With primal vector segments, the order of endpoints is irrelevant. The required order of endpoints for half-plane or raster segments gives the segment an implicit direction. Any explicit treatment of direction (e.g.

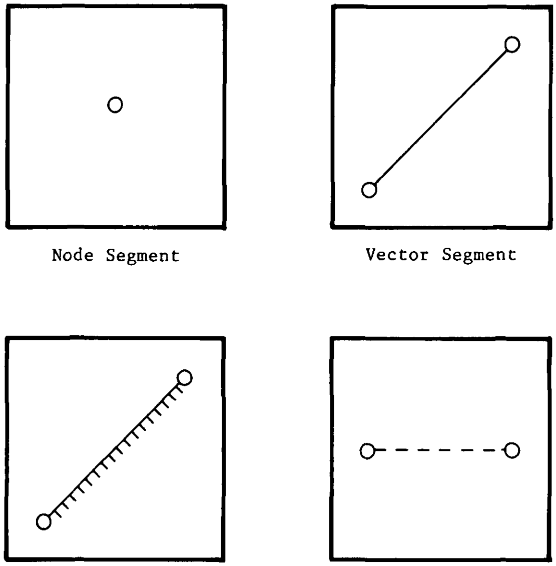


Figure 1. Primal level elements

streamflow, one-way streets) is considered an attribute of the segment and should be treated separately in the data structure.

The uniform format allows for sets of primal elements to be easily grouped into 'stacks'. An arc entity can be represented by a stack of vector segments. Alternatively, a stack may represent a network of arcs. Similarly, a polygon, or a group of polygons, can be encoded as a stack of half-plane or raster segments.

Given the desire for minimal structure, the order of the individual elements within a stack is considered arbitrary. Moreover, stacks may consist of primal elements of differing types. The objective at the primal level is to develop operators that act upon pairs or individual primal elements such that their repeated application for a stack(s) supports respective higher level geometric operators.

Some obvious candidates for monadic primal operators include the following:

LENGTH: The length of each vector segment is computed and accumulated.

AREA: The area below each half-plane segment (to some arbitrary lower limit) is computed and accumulated. The area figure is added and subtracted from the accumulator for segments in a +X and -X direction respectively.

BOUNDARY: The element type code for each half-plane segment is changed to indicate a vector segment.

PERIMETER: Invoke BOUNDARY and LENGTH operators for each half-plane segment.

COMPLEMENT: Reverse order of endpoints for each half-plane segment.

In each case, the order of the elements in a stack is irrelevant, as is the number of geometric entities represented by the stack.

Formulating dyadic primal operators, not surprisingly, is more complex. There are numerous ways in which a pair of primal elements may relate to one another; some of the permutations are illustrated in Figure 2. Primal operators can be developed to test for these types of relations and return the appropriate logical or graphic result.

In some instances, the result of a primal operator can be directly related to a geometric relationship. For example, 'true' results for a test of relations (C.2), (D.3), or (D.4) in Figure 2 would indicate that a node falls upon a polygon boundary.

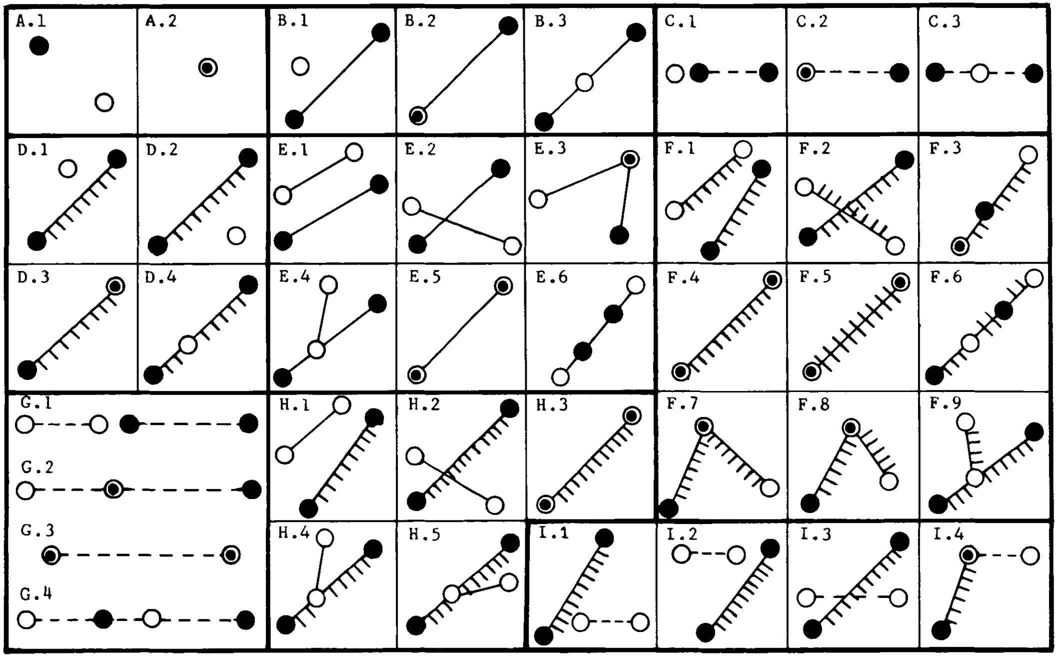
Determining if a node falls within a polygon is a straightforward test for polygons represented by raster segments, as illustrated in relation (C.3). For half-plane segments, the test requires more steps. A ray can be extended in one direction from the node and a count maintained of the number of intersections with half-plane segments. If odd, the node is inside; otherwise the node is outside.

This process of determining the parity of intersections with half-plane segments serves also to determine if other disjoint primal elements are within polygons represented by half-plane segments. The process is simply applied to each endpoint.

Primal operators for raster-to-raster relations (G.1) to (G.4) can be modeled after standard raster processing methods. Steps for determining union, intersection, difference and the like are straightforward.

Primal operators to test for vector-to-vector relations (E.1) to (E.6) are less straightforward than that for raster segments. A bounding rectangle test would determine the possibility for intersection. Endpoint equality test would detect relations (E.3) and (E.5). Finally, solving the two simultaneous linear equations would determine any interim points of intersection (e.g., (E.2),(E.4), and (E.6)).

The same steps used for vector segments are applicable for testing relations among half-plane segments, but with an additional consideration for direction. For example,



A: node-node relations
B: node-vector relations
C: node-raster relations
D: node-half plane relations
E: vector-vector relations
F: half plane-half plane relations
G: raster-raster relations
H: vector-half plane relations
I: raster-half plane relations

Figure 2. Sample relations between primal elements

relation (E.5) represents coincidence for the vector segments. A respective result for half-plane segments requires a subsequent step to determine actual coincidence (F.4) or adjacency (F.5).

Primal operators for half-plane segments that in part support polygon overlay can be illustrated with relation (F.2). Given relation (F.2), operators for union, intersection, and difference would return the subdivided half-plane segments as illustrated in Figure 3. These steps would have to be augmented to detemine the disposition of disjoint half-plane segments (i.e. inside, outside) in a manner similar to that for node segments described above.

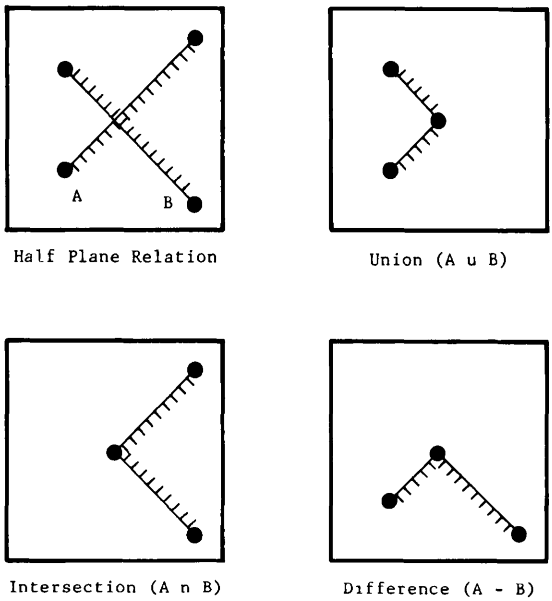


Figure 3. Primal operators related to polygon overlay

By extending the formulation of primal operators to handle elements of different types, tests can be made for relations illustrated by relations (H.1) to (I.4). This capability would serve to support the overlay manipulations of polygons in alternative representations and the overlay of polygons with network configurations and point distributions. The stacks may be designed to accommodate primal elements of different types. Two such stacks can be manipulated given primal operators defined for elements of different types to produce a resultant stack.

Considered in total, such stacks are much like the geometric data type discussed above. A dimensional select-type operator can sift through the resultant stack, piecing together desired higher level constructs (e.g., arc, polygon).

SUMMARY

The tendency to focus upon geometric elements and operators based upon the dimensionality of space is perhaps due to the straightforward manipulations of these elements on a conceptual level. Given the necessity for continuous geometric elements to conform to a discrete, sequential computer storage, our purview should be extended to a primal level that exploits the discrete qualities of spatial data representations. By formulating a primal operator that has geometric significance, yet employs a minimal structure, its utility is independent of any particular data structure.

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MAPS OF SHADOWS FOR SOLAR ACCESS CONSIDERATIONS

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BIOGRAPHICAL SKETCH

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ABSTRACT

A computer program for shadow mapping has been developed at the University of Wisconsin. The program is intended as a tool for site-selection and planning purposes when access to sunlight is a design criterion. The program operates on two files which have a common three-dimensional reference system: 1) a DTM file, and 2) an "improvements" file. The "improvements" file contains X,Y,Z coordinates of structures and other physical features. Given the altitude and azimuth of the sun, the program will plot the shadows which the improvements cast upon the DTM. The program is also capable of mapping shadows which the terrain casts upon itself. In order to assess the accuracy of the mapping algorithm, two tests have been made. In the first test, computer-generated shadows of structures were compared to shadows mapped from aerial photography on a stereoplotter. In the second test, positions of computer-generated shadows of the terrain itself were compared to those obtained by ground survey.

INTRODUCTION

With recent advances in technology and inevitably declining supplies of fossil fuels, the practical use of solar energy has become more and more attractive. Associated with this trend is the recognition of the value of sunlight and the need for protecting individual rights to the sun. Solar access may be protected by granting easements (Franta,1980), (McLaughton,1980), by zoning, or by including restrictive covenants in the owners' certificates of new subdivisions (Hayes,1979).

Specialized surveying instruments and photogrammetric techniques (Elgarf,1981), (Colcord,1982) have been developed for positioning solar collectors in shade-free areas and for locating individual solar easements. Planning and design of solar subdivisions have been done using templates of shadows placed upon maps (Erley and Jaffe,1979) and physical models of structures and terrain illuminated by a light source simulating the sun (Knowles,1980). The process of planning solar access was partially automated by Arumi and Dodge (1977). They developed software for generating building height limits for solar access in an urban redevelopment project.

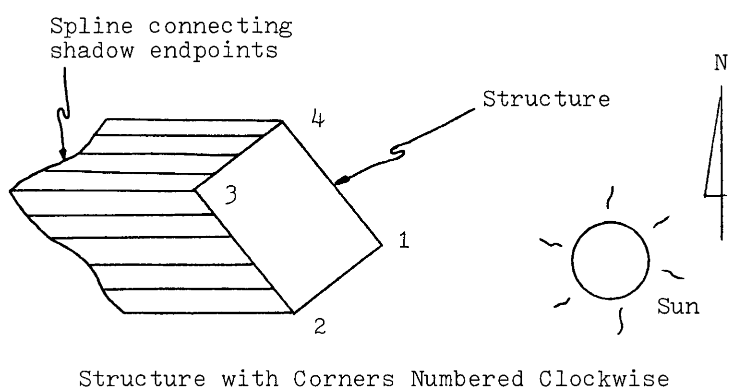
The computer program described herein is intended as a general tool in collector site-selection and in the large-scale design of subdivisions. Given three-dimensional models of terrain and structures, maps of shadows for any solar azimuth and altitude may be produced. The program should be particularly useful when a large scale topographic map, usually required for subdivision design, is already available. Such a map can supply the needed digital terrain model.

THE MAPPING ALGORITHM

Shadows of Structures

In order to map the shadows of structures, the algorithm requires a DTM and an "improvements" file containing X,Y,Z coordinates of building corners. The DTM must be on a uniform grid. The improvements file may contain 1) real data, in which case the application is solar collector site-selection, or 2) fictitious data, in which case the application is planning and design. The azimuth and altitude of the sun are required as additional input.

The corners of each structure must be numbered consecutively clockwise. As illustrated in Figure 1, any wall of a structure casts a shadow if the sun lies to the right of the plane containing the wall as the building is traversed clockwise. No shadow is cast if the sun lies to the left of that plane. Shaded areas are located by scanning along profiles in vertical planes which are separated by even increments along walls which cast shadows.



Structure with Corners Numbered Clockwise

Figure 1.

Figure 2 illustrates the manner in which the endpoint of a shadow in a given profile is found. The elevations of points A and B, on the perimeter of a DTM grid cell, are found by assuming a linear slope between the adjacent grid corners. The vertical angles, α, from A and B to the point casting shadow are computed. Let

$$\alpha_S = \text{solar altitude.}$$

If

$$\alpha_A > \alpha_S \quad \text{and} \quad \alpha_B > \alpha_S ,$$

both A and B are in shadow and scanning along the profile continues. If

$$\alpha_A > \alpha_S \quad \text{and} \quad \alpha_B < \alpha_S ,$$

the shadow ends within the grid cell and the endpoint is found by iterative interpolation. The first approximation (L) for the endpoint is found on the line AB where

$$\alpha_L = \text{solar altitude.}$$

The elevation of the DTM at that point (A') is computed by inverse weighted distance between the four surrounding grid cell corners. The second approximation (L') lies on the line A'B. The process continues until the difference in elevation between the latest approximation and the DTM becomes negligible at C. Once the shadow endpoints for a given wall are computed, they are connected by a spline curve as illustrated in Figure 1.

Figure 3 shows computer-generated shadows cast by a building upon fictitious terrain for three positions of the sun. The three solar azimuths are 135°, 180°, and 225° with respective solar altitudes of 12°, 30°, 12°. These are approximate values for 9:00 AM, 12:00 PM, and 3:00 PM on the winter solstice at a latitude of 36½° N. The winter solstice is commonly used for design because that is the time at which shadows are longest. In Figure 3 the lengthening of shadows in the terraced depression and the shortening of shadows on the terraced hillside can clearly be seen.

Shadows of Terrain

Shadows cast by the terrain itself are found in a manner similar to those cast by structures except that profiles covering the entire DTM are scanned. Profiles for morning shadows are begun along lines connecting the centers of the easternmost tier of grid cells and the centers of the southernmost tier of grid cells. Profiles for afternoon shadows are begun along lines connecting the centers of the westernmost tier of grid cells and the centers of the southernmost tier of grid cells. With reference to Figure 2, as the perimeter of a grid cell is intersected, if the vertical angle from point B to point A is greater than the altitude of the sun, then A casts a shadow on B. The endpoint of the shadow cast by A lies in another cell along the profile being scanned and is found in a manner similar to that of the endpoints of shadows cast by structures.

Figure 4 illustrates shadows cast by terrain upon itself for

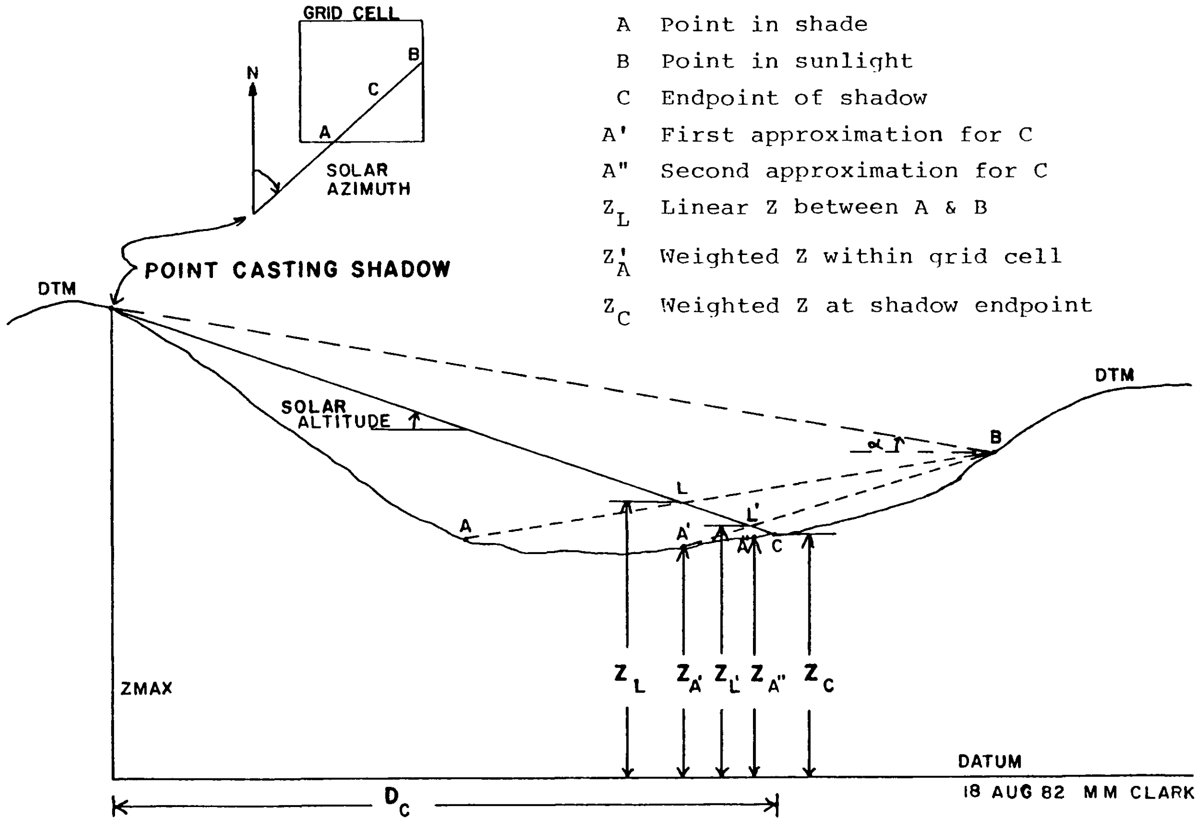
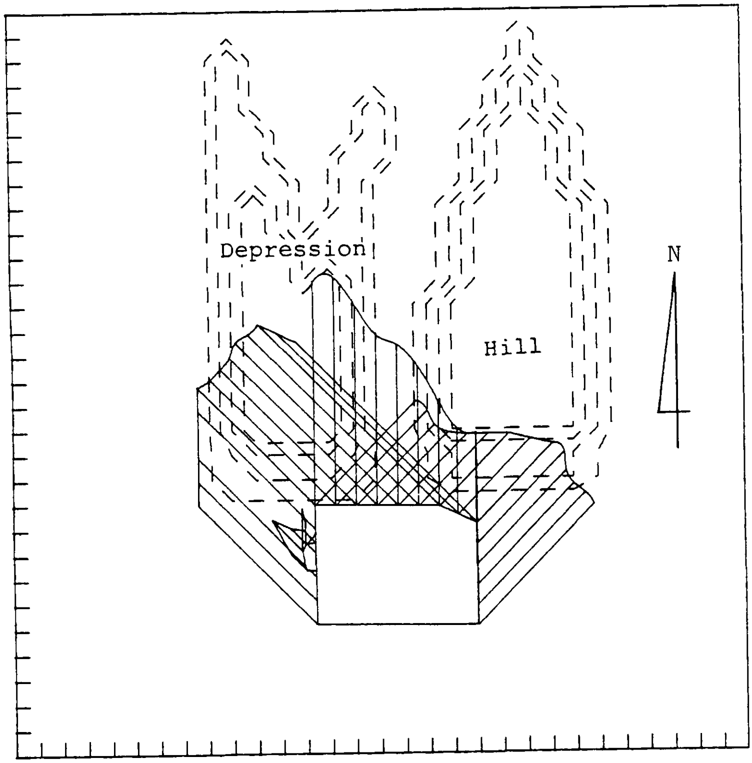


Figure 2. Interpolation for Shadow Endpoint.



Three Positions of the Sun on Building with Porch and the Effect on Varied Terrain. Contour Interval 10 ft.

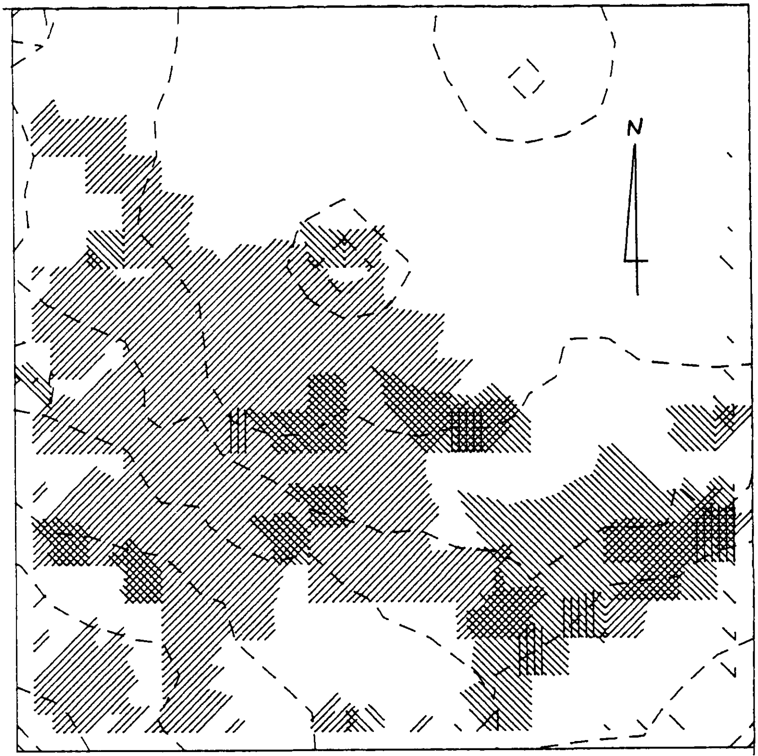
Figure 3.

the same three positions of the sun used in Figure 3. There are hills in the north-central, southeastern, and southwestern parts of the map. There is a shallow valley which runs northwest-southeast. Areas which are shaded for various parts of the day can be seen. A few small areas are in shadow throughout the day. The peak in the north-central part of the map is in sunlight all day long, but is surrounded by shadows, some of which are cast by itself, in the morning and afternoon.

COMPARISON TO MEASUREMENTS

Shadows of Structures

In order to provide a basis for comparison of computed shadows to measurement data, a map of shadows cast by structures was compiled on a Kern PG2 stereoplotter. Existing aerial photography, taken at approximately local noon on November 6, 1974, was used to form a single stereomodel at a scale of 1:720. This photography was ideal in that ground control was already available and the shadows of structures were sharply defined. A portion of the map from the stereo-



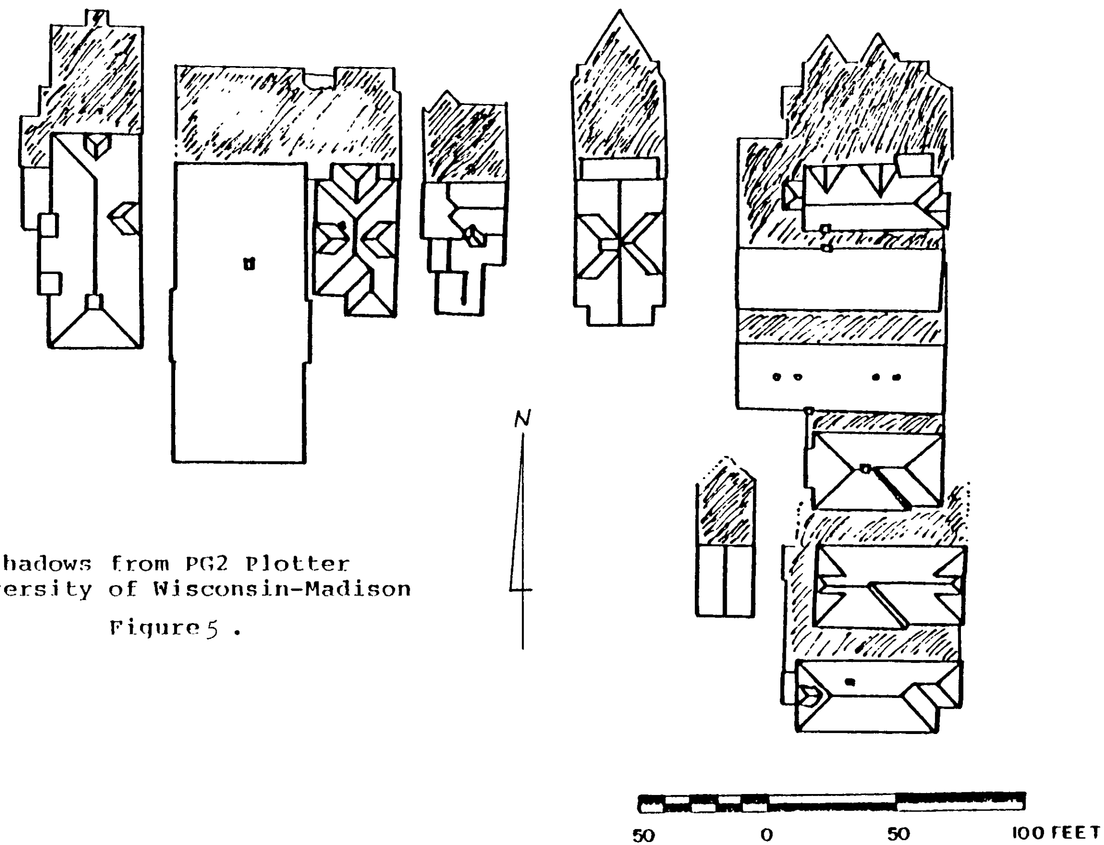
Three Positions of the Sun with the Sample Terrain
Casting Shadows on Itself
Contour Interval 10 ft.

Figure 4.

plotter appears in Figure 5.

The stereoplotter is equipped with a digitizer. As the map was being compiled, model coordinates of control points, building corners, shadow corners, and random spot elevations were recorded. The parameters of a three-dimensional, conformal coordinate transformation were computed by a least squares fit to the ground control. The measured model coordinates were then transformed into a ground-scale system.

A digital terrain model, on a uniform grid, was then produced by inverse weighted distance interpolation to the four data points nearest each grid cell corner. The shadow mapping algorithm was then employed to generate the map which appears in Figure 6. Since the exact time of photography was not known, the azimuth of the sun (0°55'53") was computed as the average direction of the shadows of a number of vertical lines in the transformed stereomodel. The altitude of the sun (31° 00'24") was then computed from the azimuth using ephemeris data.



Shadows from PG2 Plotter
University of Wisconsin-Madison

Figure 5 .

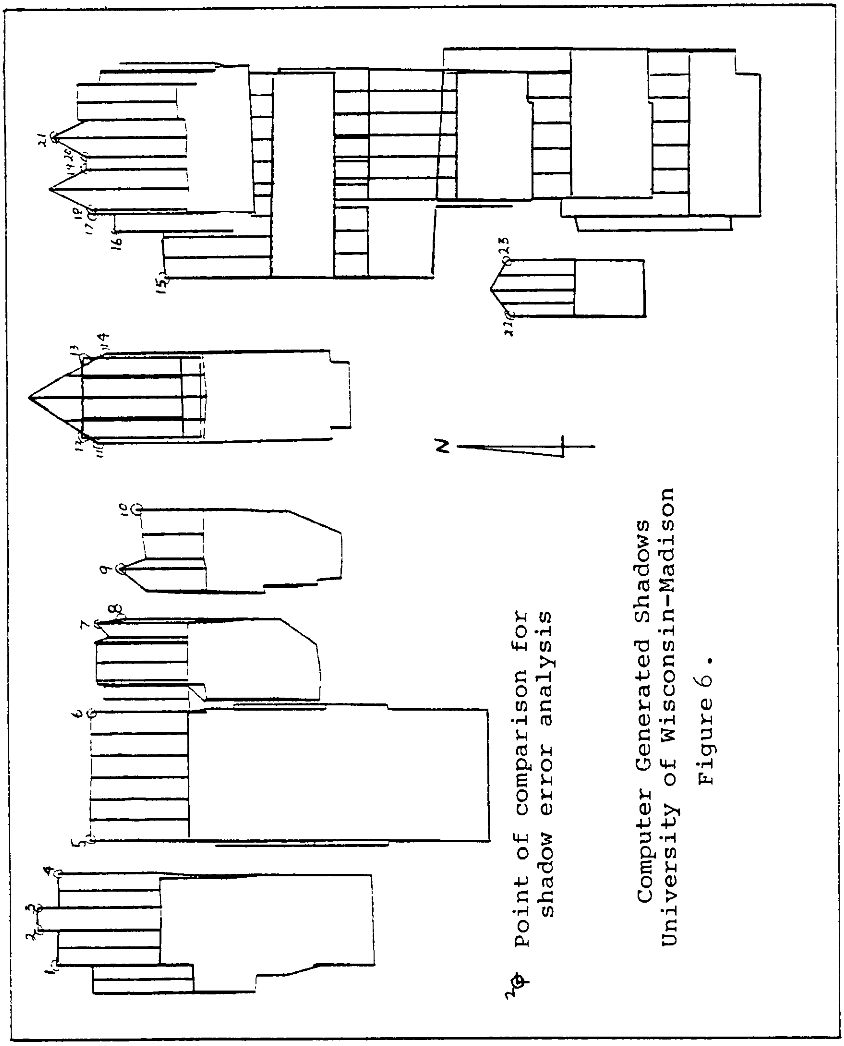


Figure 6.

Figure 6 indicates twenty-three sharply defined points which were used to obtain the data in Table 1. That table contains the discrepancies, at ground scale in feet, between coordinates of shadow endpoints as measured on the stereo-plotter and as computed by the mapping algorithm. Since the sun was nearly on the local meridian, it is the discrepancies in the Y coordinates which most nearly reflect the errors in the lenghts of shadow lines. These discrepancies also are indicative of the errors in the planimetric positions of the shadow endpoints on the computer-generated map. The mean discrepancy in Y indicates bias introduced by systematic errors in the DTM and error in the computed altitude of the sun. The corresponding standard deviation reflects random error in the DTM.

Table 1.

Discrepancies Between Stereoplotter Shadow Coordinates and Computer-Generated Coordinates (Units are Feet)

Point	Delta X	Delta Y	Delta Z
1	0.1	2.6	-0.2
2	0.2	1.7	0.0
3	0.2	1.4	0.1
4	-0.1	1.7	-0.5
5	0.5	-0.2	0.8
6	-0.6	-0.8	0.3
7	0.2	1.1	0.1
8	0.7	3.1	0.6
9	0.2	2.2	0.1
10	0.2	2.0	-0.3
11	0.0	-2.7	-0.2
12	-0.1	-2.1	0.0
13	0.0	-1.4	-0.1
14	0.6	0.0	0.2
15	0.0	1.0	-0.7
16	-0.4	2.3	-0.3
17	0.2	2.1	0.2
18	0.4	2.1	0.2
19	-0.4	0.4	0.0
20	0.1	0.3	0.0
21	-0.3	-0.2	0.0
22	-0.3	0.2	0.0
23	0.0	0.0	-0.2
Mean	0.0	0.7	0.0
Std. Dev.	0.3	1.5	0.3

Shadows of Terrain

Soldiers Grove, Wisconsin is a small community in the southwestern part of the State. Its residents are unfortunate enough to live and do business in the floodplain of the Kickapoo River. Just recently it was decided to escape the river by moving the entire community approximately one kilometer. The village board showed foresight by requiring that the new businesses and residences be equipped for solar energy. The new town-site is just north of the base of a very steep and high bluff. Layout of the town-site required knowledge of the position of the shadow cast by the bluff. Design was based upon the edge of the shadow cast at 2:00 PM on the day of the winter solstice in 1981 (solar azimuth = 208°22!6, solar altitude = 17°52!3). Soldiers Grove provided a fine opportunity for the testing of shadows cast by terrain.

A topographic map, at a scale of 1:600, was prepared from a stadia survey of the site. The orientation of the map was controlled by a solar azimuth which was checked by running traverse to a triangulation station approximately three kilometers distant. The contours on this map (contour interval = 10 feet) were digitized at a resolution of 0.001 inches. A digital terrain model, on a uniform grid, was generated by inverse weighted distance from the digitized contours.

A ground survey of the design shadow line was performed in July of this year. The theoretical shadow line was located by running, in the direction of the design azimuth of the sun, along offsets from a baseline. The endpoint of each offset was taken to be the place where the vertical angle to the tops of trees atop the bluff equaled the design altitude of the sun. An estimate of the heights of the mature hardwood trees (60 feet) was obtained from the Crawford County Forester. The computer-generated terrain shadow line, the ground surveyed tree shadow line, and a terrain shadow line based upon tree heights could then be plotted (see Figure 7). Due to errors in the survey, it is estimated that the uncertainty in the tree shadow line is ± 4 feet in the design azimuth of the sun. If the estimate of the tree heights is uncertain by ± 5 feet, the corresponding uncertainty in the ground surveyed terrain shadow is ± 16 feet in the azimuth of the sun.

CONCLUSIONS

A computer program for shadow mapping has been developed at the University of Wisconsin. The program is intended for use in solar collector site-selection and in subdivision design.Tests indicate that the shadows of structures can be mapped to within 2.5 feet. A comparison of shadows of terrain as surveyed and as mapped by the program has also been made.

The results reported herein should be regarded as preliminary. The stereoplotter map and the computer map of structure shadows are not totally independent because the solar altitude used on the computer map was computed from an azimuth taken from the stereoplotter. The authors hope to repeat the described test using aerial photography for which the time of exposure is known precisely. The authors also intend to return to Soldiers Grove in winter when the shadow cast by the large bluff can be mapped directly.

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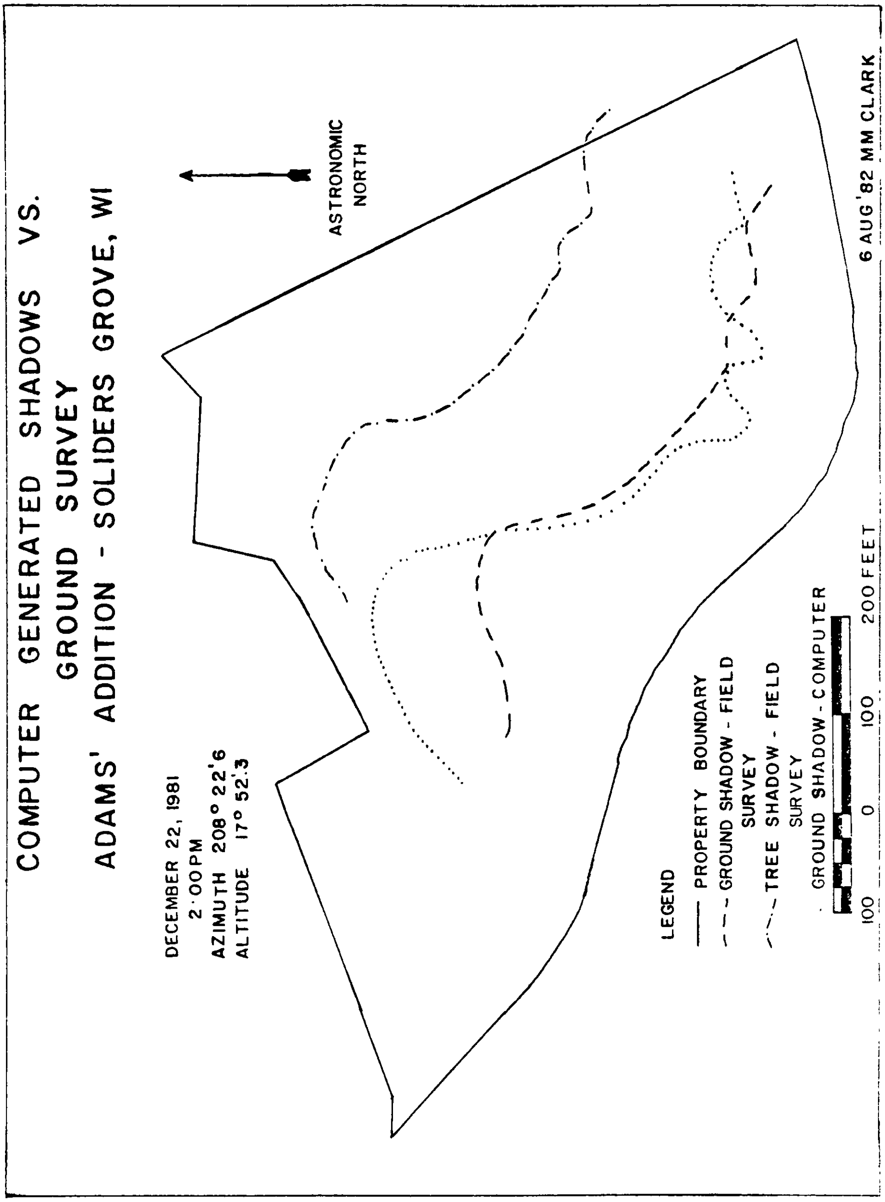
COMPUTER GENERATED SHADOWS VS.
GROUND SURVEY
ADAMS' ADDITION - SOLIDERS GROVE, WI
DECEMBER 22, 1981
2:00PM
AZIMUTH 208° 22'6
ALTITUDE 17° 52'3
ASTRONOMIC NORTH
LEGEND
PROPERTY BOUNDARY
GROUND SHADOW - FIELD SURVEY
TREE SHADOW - FIELD SURVEY
GROUND SHADOW - COMPUTER
100
0
100
200 FEET
6 AUG '82 MM CLARK

Figure 7.

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THE APPLICATION OF CONTOUR DATA FOR GENERATING HIGH FIDELITY GRID DIGITAL ELEVATION MODELS

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ABSTRACT

Digitized contours are increasingly being applied as a data source for generating regular grid digital elevation models (DEMs). The special characteristics of contours as a DEM data source, and some published contour-specific interpolation algorithms, are reviewed in this paper. Test results for three algorithms are presented, employing both synthetic and real surface data. The algorithms are: linear interpolation with four data points found in the grid axis directions (LIXY), linear interpolation within two data points found in the approximate direction of steepest slope (LISS), and cubic interpolation within four data points found in the approximate direction of steepest slope (CISS). The results indicate that high fidelity DEMs can be generated from contours, particularly when associated terrain features, such as break lines, ridges and spot heights, are incorporated into the input data. The root mean square errors of interpolated heights, relative to the contour data, range from 3% to 27% of the contour interval, depending on the interpolation algorithm, surface structure, and composition of the input data. Error surface contours are employed to illustrate the extent of systematic errors in the interpolated DEMs. The fidelities of the DEMs interpolated by means of the steepest slope algorithms are significantly higher than those resulting from grid axis interpolation.

INTRODUCTION

Contours are currently employed as a data source for the production of grid DEMs by government (civil and military) and commercial mapping organizations (Boyko, 1982; Adams et al , 1980; Leberl and Olson, 1982). Two reasons may be identified for the increasing popularity of this data source. Firstly, contours are either already available in graphic form on topographic maps, or can be readily obtained in a digital or graphic form directly from a stereoplotter. In these cases, the grid DEM can be generated by digitizing the graphic contour data, and applying an appropriate interpolation algorithm. Secondly, the special characteristics of contours as a terrain descriptor may be exploited by an interpolation algorithm for efficient production of a high fidelity DEM.

The fidelity of a DEM is a function of both the accuracy of the individual DEM elevations, and the geomorphological information content of the total model. In this paper, the accuracy of individual elevations are expressed through the

RMSE of interpolated heights, given as a percentage of the original contour interval (% CI), while the extent to which the geomorphological information in the original contours is captured in the DEM is illustrated with error surface contours. (A high fidelity DEM should produce error surface contours with a random horizontal and vertical distribution). Together, the RMSE % CI and error surface contours provide a measure of fidelity which is independent of the DEM density and applications.

CONTOURS AS A DEM DATA SOURCE

In a recent review of DEMs, eight patterns were identified for photogrammetric sampling of elevation data (Torlegard, 1981). These patterns consist of selective, homogeneous, progressive, composite and random sampling, in addition to sampling along profiles, contours, and epipolar lines. The contour line sampling pattern incorporates many of the desirable characteristics of the other patterns. The pattern is selective in that spot heights, break lines, ridges, drainage lines and other significant features are either implicitly or explicitly recorded during contour compilation. Contour sampling may be described as homogenous as all parts of the stereomodel are considered, and as progressive, since the density of the data is increased in areas of rough terrain. The contour pattern may be considered a special case of either composite or profile sampling, with the additional feature that the original data satisfy a wide range of applications without further processing.

These characteristics of contour sampling result from the sampling scheme being defined in terms of elevation differences, which is one of the phenomena being recorded. The structure of the contour lines is dependent on the local geomorphology, while the contour interval places a limit on the range of possible unrecorded elevations. Other commonly applied sampling patterns such as homogenous grids or profiles are not phenomenon based, and so no information on the shape or elevation of the terrain between observed points or lines can be inferred.

CONTOUR-SPECIFIC INTERPOLATION ALGORITHMS

Digital contour data may be processed by any general interpolation algorithm, such as the moving surface or finite elements methods, by considering the data as a set of randomly distributed point observations. However, these methods are generally less efficient and less accurate than contour-specific methods, as the former do not exploit the characteristics of contour data.

The published contour-specific algorithms may be classified into four groups, based on the methods employed to locate contour data points and interpolate within those points. The four groups are:

1. Linear interpolation within data points found in prespecified axis directions (LIXY). The number

of axes may be one, two or four, leading to two, four or eight data points.

2. Linear interpolation within two data points found in the direction of steepest slope through the DEM point (LISS). The directions searched for the steepest slope may be limited to the x, y and two diagonal axes. A variation of this algorithm employs the distance transform method to locate the two data points, hence allowing the local steepest slope profile to change direction at the DEM point (Mordhorst, 1976; Leberl et al, 1980).

3. Cubic polynomial interpolation within four data points found in the direction of steepest slope through the DEM point (CISS). As with LISS, the number of directions searched for the steepest slope may be limited.

4. Other algorithms. This group includes an investigation into the application of least squares interpolation (collocation) on data points found in pre-specified axis directions (Lauer, 1972), and algorithms which employ parallel processing hardware and procedures. The parallel algorithm described by Adams et al, 1980, applies linear interpolation to data points selected from the current processing column, the data to the right of the current column, and from within interpolated DEM points to the left of the column.

A summary of the published algorithms, grouped under these four classifications, is presented in Table 1. The table lists the authors, date of publication, the results of any accuracy tests, and the standard for accuracy testing. The title and source of each publication are listed in the references. Figure 1 illustrates the data points used by a representative algorithm from each classification. Since the published test results are not based on the same input data or test standard, and the algorithms within each group are not identical, the accuracy results cannot be directly compared and should be treated only as an indication of the accuracies which can be obtained with contour data. The published results relating to the geomorphological information content of contour-interpolated DEMs have been limited to comparisons of re-interpolated contours with the originals.

Many of the references listed in Table 1 indicate that the inclusion of supplementary non-contour data, such as spot heights, break lines, and ridge and drainage lines, significantly improves the fidelity of interpolated DEMs. One implementation of the two axis LIXY algorithm computes "phantom" data points to model hill tops, valleys and ridges

TABLE 1

Published Contour-Specific DEM Interpolation Algorithms

Algorithms are grouped according to the method used for locating data points, and performing the interpolation. Accuracy results have been converted to the RMSE of interpolated heights as a % of the contour interval.

AUTHORS	DATE	RMSE % CI	STANDARD
1. Linear along prespecified axes (LIXY).			
Lauer	1972	8%-16%	manual int'n
Schult	1974	19%-34%	*
Finsterwalder	1975	15%-19%	stereo obs'n
Yoeli	1975		
Boyko	1982	<50%	ground obs'n
Leupin and Ettarid	1982		
2. Linear in direction of steepest slope (LISS).			
Hallmen	1969		
Finsterwalder	1975	13%	stereo obs'n
Yoeli	1975		
Mordhorst	1976		
Leberl, Kropatsch & Lipp	1980	5%-10%	manual int'n
Leberl and Olson	1982	10%-20%	manual int'n
3. Cubic in direction of steepest slope (CISS).			
Clarke, Gruen and Loon	1982	3%-10%	synthetic surface
4. Other algorithms.			
Lauer (collocation)	1972	5%-13%	manual int'n
Clark	1980)		
Adams , Anderson, et al	1980)	(parallel processing)	
Baker, Gogineni, et al	1981)		

* heights interpolated from the DEM at contour locations

(Boyko, 1982). The CISS algorithm includes a special procedure for interpolation adjacent to a break line, whereby data points beyond the surface discontinuity are not employed for the interpolation. The pre-processing of data for the CISS algorithm includes procedures for incorporating spot heights and structure lines into the interpolation data set. A more detailed description of the published contour-specific interpolation algorithms, and of the development and implementation of the CISS algorithm, may be found in Clarke, 1982.

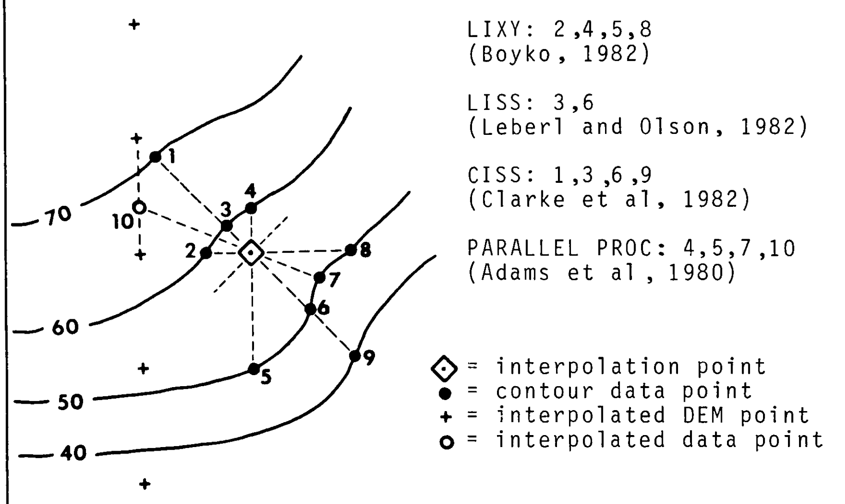

Figure 1: Data points used by four contour-specific DEM interpolation algorithms.

EXPERIMENTAL RESULTS

Three of the algorithms from Table 1 have been programmed in FORTRAN, employing a raster data format. The algorithms are LIXY with two axes and four data points, LISS with four directions searched for the steepest slope, and CISS, also limited to a four direction search. Results from the application of these algorithms to synthetic surface data have been published previously (Clarke, Gruen and Loon, 1982). In that investigation, the RMSEs of interpolated points were found to be 3% CI for CISS, 15% CI for LISS, and 21% CI for LIXY. The error surface contours from the LISS and LIXY DEMs both exhibited a trend similar to the original surface, while the CISS error contours were randomly distributed, at the 10% CI level.

Two areas from a 1:25,000 scale topographic map (20 m contours) have been digitized with a manual line following digitizer, for the real surface testing of the algorithms. For each 50 mm by 50 mm map area, two raster data sets were created; one containing only contours, and the other containing contours, ridge lines, break lines (streams) and spot heights. Elevations along the non-contour linear features were computed during the vector to raster conversion, employing contour intersections as the data points for natural cubic spline interpolation. Spot heights were incorporated into the "all-data" rasters by interpolating a line of elevations between the spot height and surrounding contour. This procedure ensures that the spot height information will be encountered during the limited direction data searches performed by the interpolation algorithms. Grid

DEMs with a 25 m ground spacing were interpolated from the four data sets, with each of the CISS, LISS and LIXY algorithms. To isolate the effect on DEM fidelity of different terrain features and the effect of the inclusion of the supplementary data, five sub-areas were selected for detailed analysis. Figure 2 shows the vector data and DEM locations within each sub-area. Grid DEM heights were compared to manually interpolated heights to produce the accuracy statistics in Table 2. Error surface contour plots have been produced for each of the algorithms, data sets and sub-areas (Clarke, 1982). The plots for sub-area 5 are shown in Figure 3. Sample computation times for the three algorithms are shown in Table 3. The shorter times when all data are included are due to the lower number of pixels which must be examined in the raster data during the search for supporting points for the interpolation at each DEM point.

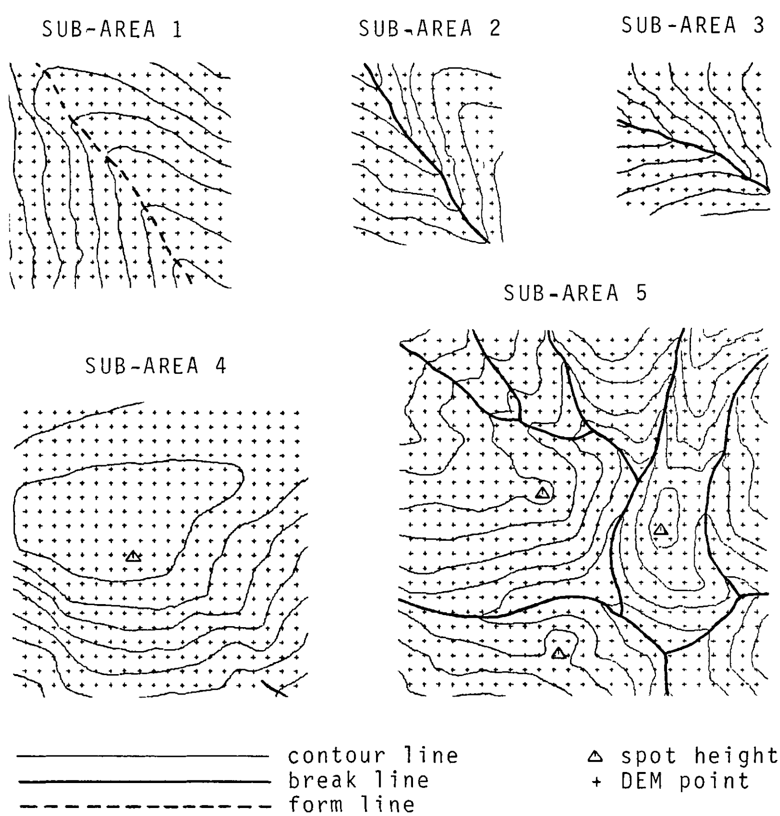

Figure 2: Sub-areas used for detailed analysis

TABLE 2

DEM Accuracy Statistics using Topographic Map Data

Input data contour interval (CI) is 20 metres.
Absolute maximum errors and RMSEs are given in metres.
See Figure 2 for the original contours in sub-areas.

ALGORITHM:	CISS		LISS		LIXY	
INPUT DATA:	CONTOUR	ALL	CONTOUR	ALL	CONTOUR	ALL
Sub-area #1 (225 points)						
Abs max error	7.0	4.2	5.0	3.4	13.0	5.3
R M S E	1.4	1.2	1.0	0.9	3.2	1.5
RMSE as % CI	7%	6%	5%	5%	16%	8%
Sub-area #2 (120 points)						
Abs max error	4.1	3.5	5.3	3.0	13.0	10.0
R M S E	1.2	0.9	1.0	0.9	3.8	2.9
RMSE as % CI	6%	5%	5%	5%	14%	9%
Sub-area #3 (100 points)						
Abs max error	6.4	3.6	5.0	3.7	9.3	9.2
R M S E	1.5	1.2	1.2	1.1	2.8	2.1
RMSE as % CI	8%	6%	6%	5%	14%	9%
Sub-area #4 (400 points)						
Abs max error	12.1	8.7	14.0	10.2	17.0	17.0
R M S E	1.9	1.6	3.8	1.8	5.4	4.6
RMSE as % CI	9%	8%	19%	9%	27%	23%
Sub-area #5 (625 points)						
Abs max error	15.3	4.1	12.0	5.0	16.0	11.5
R M S E	2.4	1.3	2.1	1.1	3.9	2.9
RMSE as % CI	12%	6%	10%	6%	20%	14%

TABLE 3

Sample Computing Times for DEM Interpolation

The times shown are the CPU times in seconds for the interpolation of 2601 DEM points within a 251 x 251 data matrix, using an Amdahl 470 V6-II computer. Program compilation and input/output are not included.

ALGORITHM:	CISS	LISS	LIXY
USING CONTOURS ONLY:	6.25	3.22	2.01
USING ALL DATA:	5.90	3.08	1.88

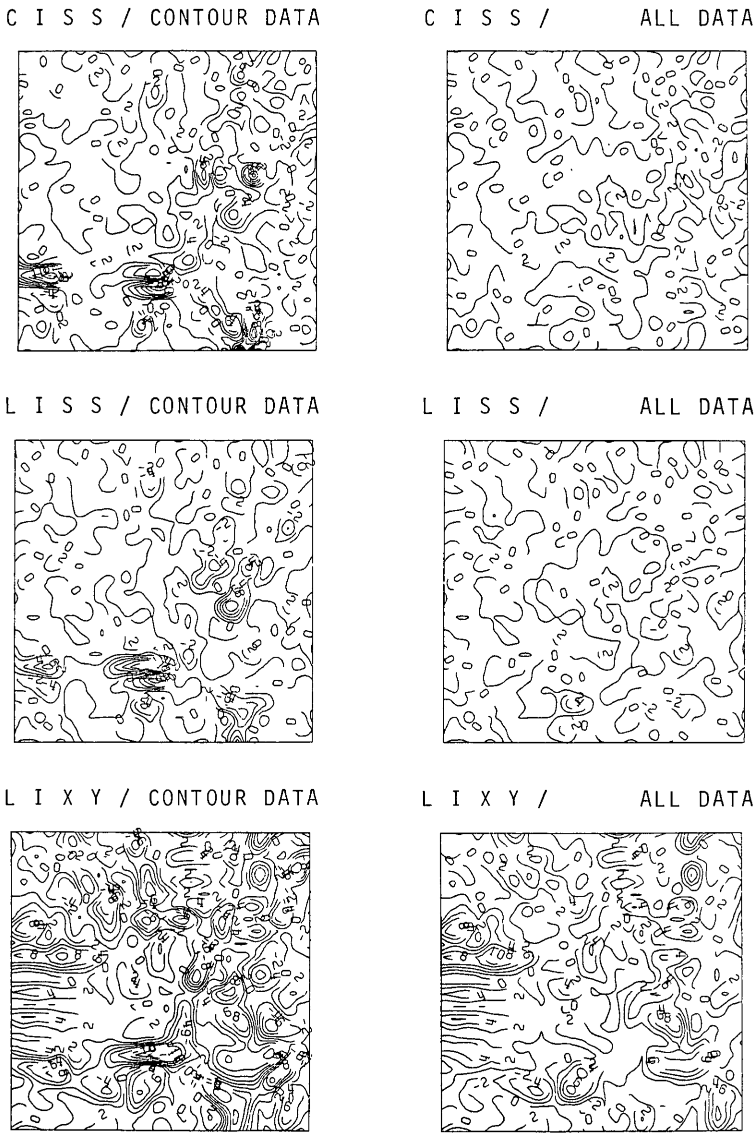

Figure 3: Sub-area #5: Error surface contours (10%CI)
Original contours are shown in Figure 2.

CONCLUSIONS

The topographic map data testing has not produced the clear ranking of algorithms, in terms of DEM fidelity, that was possible from the synthetic surface results. Overall, the two steepest slope algorithms have performed equally well and always better than LIXY. The only situation which demonstrates a clear difference between CISS and LISS is sub-area 4, where without supplementary data, the CISS algorithm was able to retain the mountain top geomorphology in the interpolated DEM. In all other cases, the statistics from the LISS algorithm were equal to or slightly better than those from CISS, although the differences are not generally perceptible in the 10% CI error surface contour plots. (The extent to which the comparison is influenced by the use of manually interpolated heights as "true" values could only be determined by more objective testing).

A clear trend in the topographic map tests is the improvement in DEM fidelity which results from the inclusion of supplementary data. The additional data have a large effect on the accuracy statistics of the LIXY algorithm, but do not eliminate the trends from the LIXY 10% CI error surface contours. The improved point accuracies however, do not equal those resulting from the application of the steepest slope algorithms to the "contours-only" data. The additional data have a lesser effect on the steepest slope accuracy statistics, but eliminate the trends in the 10% CI error contours, indicating a high retention of the geomorphological information contained in the original data. From the contour data employed in this study, the expected RMSE of DEM heights, relative to the original data, is 5% to 15% CI when steepest slope algorithms are applied, and 14% to 27% CI when the x,y axes algorithm is applied. Smaller errors and a higher retention of geomorphological information may be expected when supplementary non-contour data are included. These results are consistent with the previously reported findings shown in Table 1.

Further investigations in this area will include modifying the CISS algorithm to search more directions from the DEM point, and to locate the outer two data points by steepest slope searches from the inner two points. (Currently, the outer two points are located by a linear extrapolation in the direction of the inner steepest slope profile). These modifications should produce more stable distributions of data points for the cubic interpolation. Additional testing will incorporate a variety of landforms, including moderately flat terrain, and employ stereomodel observations as the standard for comparison.

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INTERFACING DIDS FOR STATE GOVERNMENT APPLICATIONS

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ABSTRACT

In 1980 the National Aeronautics and Space Administration (NASA) developed a low cost remote terminal to operate the Decision Information Display System (DIDS) software and communicate with the DIDS host computer. DIDS is an interactive, menu driven, statistical mapping system that produces single and bivariate color choropleth maps for various geographical areas. The key to its use has been the linkage to a large Federal statistical data base maintained by the White House Office of Planning and Evaluation. As part of NASA's efforts to evaluate the utility of DIDS for state government applications, a remote DIDS terminal has been operating in South Carolina since December 1980. This paper will present an update on the experiences of researchers at the University of South Carolina and the State Office of Geographical Statistics with the use of DIDS and their recent efforts to link the system to other computer graphics display processes.

INTRODUCTION

In 1978 NASA and the Bureau of Census, acting upon a request from the Executive Office of the President, developed an interactive color statistical mapping system which evolved into the present Decision Information Display System (DIDS) (Zimmerman 1980). The system incorporated a menu-driven approach to generate choropleth and bivariate maps through color image processing. This much publicized system has demonstrated the technical feasibility of such a dedicated map making machine. Perhaps more importantly the DIDS experience has raised serious questions regarding the value of such maps and their role in the decision making process. This paper will present a brief update on the current status of the DIDS program itself, the results of an evaluation of the use of a DIDS terminal in a state setting, and an outline of an approach to modifying the system to make it more responsive to state and local agency needs.

DIDS UPDATE

After having been succesfully demonstrated for the President and Congress in 1978, the DIDS system proceeded on a somewhat erratic course through a number of bureaucratic arrangements with its future still remaining uncertain. The original hardware configuration at the Goddard Space Flight Center has been replaced by a VAX 11/780 host computer that is currently operated as part of the Office of Planning and Evaluation of the Executive Office of the President. After initial efforts to organize a large scale interagency cooperative arrangement, consisting of numerous remote terminals and a massive data base, were less than successful, the Federal DIDS activity was greatly curtailed. As of October 1, 1982, there will no longer be an interagency program conducted on a central host system. The White House will be operating DIDS as part of its internal information system, abandoning the role of DIDS within other agencies to the individual decisions within those organizations. The Departments of Health and Human Services and Transportation are operating DIDS terminals; each is presently grappling with approaches for establishing a system for operating DIDS once the White House connection is severed.

Since its inception DIDS has consisted of separate elements of hardware, software and the data base. While this latest organizational change means that there will no longer be a Federal effort to establish and maintain a unified data base, its absence does not prohibit an organization from utilizing the other elements. In fact, a private company, DIDS-CO, is operating specifically to provide support to groups interested in establishing a DIDS facility. Another group, Data Resources Incorporated, is supplying data that is directly compatible with DIDS, as well as selling DIDS output products on a service bureau basis on its DADS system (Borrell 1982). The hardware components are commercially available from the De Anza Division of Gould. The original software is available through COSMIC, NASA's software distribution center. Recently a more flexible version of the software, including an expanded color palette, keyword searches and an interface to SPSS, has been developed by General Software Corporation and is running at the three federal locations. It should also be noted that the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia has taken the original DIDS hardware configuration and developed its own software, COLOURMAP, that is considerably more flexible than DIDS (CSIRO 1982).

SOUTH CAROLINA INVOLVEMENT

As originally conceived, DIDS was envisioned to consist of a centrally maintained computer that would serve as the host for a large network of remote terminals. In fact, the LSI version that would be linked via a telephone line vastly expanded the potential user community. In 1980 NASA selected South Carolina as the site to examine the feasibility of the network concept within state government setting. The project was jointly conducted by the Social and Behavioral Sciences Laboratory of the University of South Carolina and the South Carolina Division of Research and Statistical Services. The Council of State Governments (CSG) was given the responsibility of coordinating efforts with other states and disseminating information.

The DIDS remote terminal hardware and software arrived in South Carolina, where it is still operational, in mid-December of 1980. The hardware configuration consists of a DEC LSI 11/23 processor with three RL01 disk drives, an alphanumeric terminal and a 19 inch high resolution (512 X 512) color monitor. The demand for hardcopy output has prompted the addition of a low speed printer and a Matrix color camera system. For approximately fourteen months the system was linked to the DIDS host via a dedicated 9600 baud communication line. Presently it is being operated in a stand alone mode utilizing approximately 300 variables stored on a data disk.

After a few months of operation at the University of South Carolina the system was moved to the State Senate Office Building where it received considerable visability for more than a year. The basic objectives of the study and an interim progress report have been presented at the Harvard Computer Graphics Conferences (Cowen and Vang 1980, Cowen 1981). A report, "State Government Applications, Pilot Study of the Domestic Information Display System in State and Local Government" has been prepared by the Council of State Governments (1982) and a final report on the South Carolina project has been delivered to NASA and will be available shortly (Cowen 1982).

EVALUATION

The evaluation aspects of the South Carolina project concentrated on the operation of the system, its software capabilities, its data base, and user perception and behavior. The highlights of the findings of the evaluation process are delineated below.

Operating Environment

Except for a few problems, the DIDS remote terminal functioned as advertized at two different locations in South Carolina, and on two separate occasions when it was demonstrated in Atlanta. If left in one location, the equipment and software would constitute a reliable and easy to use system that could be operated by non-technical staff. The menu system is easy to comprehend and simple to use. A novice can produce a map using the defaults in a matter of seconds. More importantly, it is also easy to utilize the options to alter the colors and class intervals, zoom, list data or highlight a particular class. The only major problems relate to the difficulty of locating some data items for the beginning and the tediousness of the process for the experienced user.

Capabilities

The DIDS terminal is actually an image processing system with a menu driven prompting system that enables the user to match a variable with the appropriate geographical base, determine the classing and color schemes and generate a picture. While the preprocessing of the geographical files into pixel locations enables images to be displayed and altered quickly it also restricts the user from varying the placement of map elements or style of text. Although the system restrictions are inhibiting, the basic design appears to have been a reasonable compromise that has not caused any noteworthy problems during the use of the system. The resolution of the monitor generates a surprisingly clear county level map of the United States and the zoom capability compensates for any difficulties with scale. While color is one of DIDS most exciting features it is also one of its most restrictive. A good color camera system that includes the use of instant film can add $15,000 to the cost of the system, however, it was found to be necessary enhancement for a system that attempts to respond to immediate requests for output products or that produces bivariate maps. Unfortunately there is no inexpensive way to produce multiple color picture copies, and the less costly 35mm slides are not always on appropriate medium for presentation, publication or research.

The class interval schemes and the color palette enabled the user to generate very usable choropleth and bivariate maps of ratio or percentage data. However, the software does not provide any option such as graduated symbols or dot distributions that are appropriate for variables that represent absolute values.

Data Base

As an organizational entity DIDS was designed to be the catalyst for the creation of a current and relevant Federal statistical data base. In fact, many people viewed the DIDS hardware as simply the means to access the data items. The fact that DIDS has not lived up to its potential is probably most directly related to the difficulties in maintaining a viable data base. After all, what good is a magical map making machine if no one is interested in the available maps? The delays in the release and entry of 1980 census data were particularly disturbing. It is inconceivable to people who have witnessed the technical wizardry of DIDS that data collected two years ago could not be viewed. It must be noted that most of the problems relating to the data base are bureaucratic in nature and therefore beyond the control of the DIDS program office. Past experience indicates that unless legally mandated it is unlikely that any multiagency data base will ever exist.

The South Carolina project was adversely affected by other aspects relating to data entry. The original system design was developed with the philosophy that each remote terminal would include the same data menus as the host, thereby enabling the retrieval of the same variables. While this philosophy permitted DIDS to function as a unified network, it also precluded local data entry, and made the remote terminals dependent on the operators of the host facility. The unclear relationship of the South Carolina project with the overall DIDS program further compounded this problem. Even though current data were gathered for the counties within the State there was never any assurance that they would be entered onto the host. While some data were entered at the start of the project, other files were never available. This obviously made the system less attractive to users in South Carolina and hurt the credibility of the project. It should be noted that there is a finite limit to the number of data menus that will fit on a disk pack, therefore, it is necessary for the operators of the host to establish priorities in terms of the contents of the data base. Although the information for 46 counties may be important to policy makers in South Carolina it has very little significance in Washington

User Perception and Behavior

When the South Carolina project began there was considerable optimism and enthusiasm. Although the vast majority of the hundreds of individuals who observed DIDS have been highly impressed with its technical wizardry, due to numerous factors the project ended as something less than an overwhelming success. The inadequate data base was without a doubt, the most restrictive factor. However, there are also several lessons to be learned regarding the general manner in which a system such as DIDS will be used.

Much to the chagrin of cartographers, the lack of success of the overall DIDS effort must be partially attributed to the low priority attributed to statistical maps. Many users actually were more interested in simply retrieving the data than in viewing the display. In fact, they were generally unfamiliar with the production of choropleth maps and more interested in finding specific values for their county than in studying spatial patterns. While they were impressed with the manner in which the class intervals and color schemes affected the appearance of the map, they preferred to have a professional operator make those decisions. Most importantly, it became evident that the system would rarely be used for decision making in a real time mode. Rather, it is viewed as part of a map making service bureau from which attractive slides and color prints could be ordered. In effect, most of the requests for services did not actually take advantage of the system's speed or manipulative features. Many users would have found it easier to have the data residing on a large central computer facility with statistical and mapping software and plotting capabilities that could be accessed through conveniently located non-graphical terminals. Furthermore, they often found a black and white electrostatic plot, which could be easily reproduced, more amenable to their needs.

Although the ability to easily produce bivariate maps is one of DIDS major features, it is not clear whether these displays will ever gain widespread acceptance. Reduced to simple two by two classifications they can produce exciting and meaningful displays. Unfortunately the concept is still so new that bivariate maps will be viewed with awe by most users who will subsequently hesitate to integrate them into their analysis.

RECOMMENDATIONS

With few exceptions, users of the South Carolina DIDS system have been intrigued and amazed with both the DIDS technology and potential. However, in order to be responsive to the information needs of users at the state level, DIDS will require several system modifications, and still may be a prohibitively expensive mapping alternative.

It was never technically feasible or even desirable for the centralized DIDS host to accommodate a remote terminal in each state. Now this possibility is not even an alternative on a limited scale.

Technically, the most realistic approach appears to be the integration of a DIDS terminal into the general data processing system available within a state. In such a configuration the terminal would essentially serve as an intelligent interactive color plotter. Geographical bases of interest within a state, including sub-county level divisions, such as census tracts and census county divisions, would comprise a separate disk to which socio-economic data could be passed as needed. This would enable a user to conduct most aspects of the analysis on a mainframe, thereby freeing the DIDS terminal to be used for those things it does best. Elements from various federal data bases could easily be integrated with locally gathered data. Most of these data could be acquired on magnetic tapes, thus eliminating the need for an expensive communication line, as well as serving as inexpensive archival files. A substantial number of variables could be stored on random access files in a form compatible with one of the major statistical packages such as SAS. These files or the output from a statistical modeling procedure could then be passed to DIDS in preparation for a working session. The DIDS terminal would be the final link in a multi-source, integrated data processing network. In such a setting, the terminal could serve as a more expanded image processing and computer graphics facility. It certainly would be possible to display and manipulate other pixel images such as a Landsat scene or generate standard business graphics.

The incorporation of some of these modifications is currently underway at the Social and Behavioral Sciences Laboratory. The first phase of this process involved extracting data from the DIDS system and integrating it with other data on the University's system. This was accomplished by writing the printer output files onto a floppy disk system which was able to communicate to the University's mainframe. The data has been used to generate a regression model of population growth and has been linked to standard computer mapping software (figure 1). The next phase will include the establishment of local data entry procedures and the creation of a geographical data files relevant to local clients

CONCLUSION

In the late 70's DIDS represented an exciting and innovative

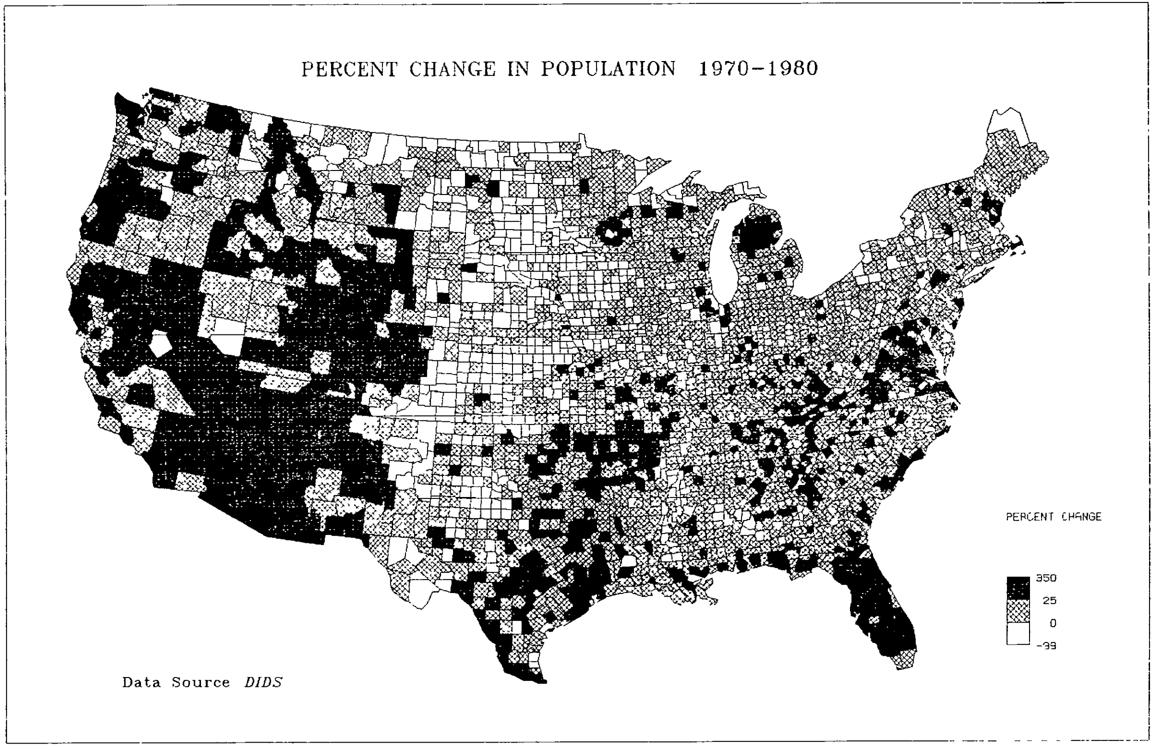

Figure 1. Electrostatic GIMMS map generated from data extracted from DIDS.

approach to computer assisted cartography designed to facilitate and support the decision making process. Now that the promise of a centralized interagency data base has failed to materialize, it remains to be seen whether the hardware and software will be able to stand on their own. Nevertheless, the DIDS experience has provided a great deal of insight regarding the design of cartographic systems. Clearly the technology capabilities exist; now the extent to which such systems will be applied, and the economic value decision makers will accord to the implementation of such systems, remain to be seen.

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1980 CENSUS MAPPING PRODUCTS

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ABSTRACT

The goals of this paper are to acquaint the reader with map products produced by the United States Bureau of the Census for the 1980 Decennial Census and to enable map users to select the appropriate census map for their use. Major categories of maps include the detailed 1980 Census Maps and the corresponding indexes, summary reference maps, and special purpose maps included in the various publication products. The paper revolves around the design and production flow of the basic map series and the subsequent evolution of derivative maps. The discussion of each series focuses on the following topics: intended purpose, format, scale, coverage, symbolization, and content. The summary briefly touches upon the automation of the mapping system in the context of long-range geographic support plans for the 1990 Decennial Census.

INTRODUCTION

The current mapping program at the United States Bureau of the Census is centered around the 1980 Decennial Census which, in the final count, will produce over 33,000 maps. The purpose of these maps is to provide a geographic framework for the data collection and data dissemination functions of the Bureau. To fulfill these functions, up-to-date coverage of the entire United States is produced in several different formats. These maps provide a great deal of information to any map user.

The maps are based upon a complicated geographical hierarchy designed to accommodate equally complex census needs. This hierarchy, combined with the sheer volume of maps and the number of different map series, results in a potentially overwhelming system of maps and mapping.

MAJOR MAP CATEGORIES

Map series produced at the Census Bureau can be divided into three major categories based upon the purpose of the series. These catgories include 1980 Census Maps, summary reference maps, and special purpose maps.

1980 Census Maps

The 1980 Census Maps provide the backbone for the census mapping program. These maps are the basis for all other maps produced, as they are the tools used in the original data collection processes. They carry no data; they are outline maps that portray the census geographic hierarchy.

The 1980 Census Map coverage is divided into five map series which, together, cover the entire United States. The five series were created to accommodate the geographic complexity of the states. They include the metropolitan map series/vicinity map series, the place map series, the place and vicinity map series, the county map series, and the American Indian reservation map series.

All 1980 Census Maps fall into one of two categories based upon the level of the geographic hierarchy portrayed on each map; the two levels are the block level and the enumeration district level. Maps that portray the block level (maps for block numbered areas) cover approximately 10 percent of the total land area of the United States, encompassing approximately 90 percent of the total population. These maps will be available in a printed format.

For the remainder of the United States, maps were prepared that carry the geographic hierarchy to the level of the enumeration district. Generally, this map coverage is provided for the less populated areas of the country. These maps are available through the Census Bureau but not, however, in a printed form.

In the published reports for block-numbered areas, two index map series have been produced--the state index to block-numbered areas map series and the standard metropolitan statistical area index to block numbered areas map series. These two indexes are summary reference maps, but are mentioned here because of their relationship to 1980 Census Maps for block numbered areas.

Summary Reference Maps

The second major category of maps include the summary reference maps. Unlike the 1980 Census Maps, which contain all aspects of the census geographical hierarchy, each of these map series focuses on a specific level of information. For example, one map series focuses on urbanized areas, another on census tracts. As the title implies, their purpose is to summarize information from the decennial census and/or to provide reference maps. They are generally at much smaller scales than the 1980 Census Maps, and were prepared to accompany the major report series prepared at the Bureau.

Special Purpose Maps

The final category, special purpose maps, consists of those maps prepared to present a specific subject or set of data. Unlike the maps of the two major categories previously discussed, these maps are generally prepared only upon the special request of a sponsoring division within the Census Bureau. They are mainly thematic maps of the United States. The unclear funding situation at the Bureau, as well as the entire Federal government, renders it difficult to predict which of these maps will be produced for the 1980 Decennial Census. In past years, published maps falling into this category include the GE50, GE70, and GE80 map series, the several United States summaries, Congressional District Data Books, and individual special purpose maps.

All the maps described above constitute the mapping products for the 1980 Decennial Census. These maps have initially been presented in the three major categories to provide a basic framework for census mapping. From this point on, however, the discussion will deviate from the three major categories where necessary, in order to provide a cartographer's viewpoint. This viewpoint focuses on the interrelationships between the major series by examining the multiple uses of base maps to produce subsequent map series. In gaining an understanding of census map products, it is important to realize that each map series is the derivative of another. The good points of each series, as well as the flaws, are carried into each subsequent map series.

The census mapping program is complex; to gain a full understanding of it, a studied effort is required. The cartographer's viewpoint (or the derivative map approach) has been used in this paper specifically to simplify the volume of information necessary to understand the mapping system. Once the information for one map is understood it can be carried over into understanding the derivative maps.

1980 CENSUS MAPS

As stated before, the purpose of 1980 Census Maps is to provide the census data user with a detailed map to accompany census data, either published in the major report series or on summary tapes. Each of the five series that fall into this category are prepared independently of any other series produced at the Bureau; they are the maps from which all other series are derived.

The five map series show the same kinds of information and therefore serve the same basic purpose. While all of the block-numbered map series are identical in content, the areas covered are mutually exclusive. Each series was designed to accommodate one of three major levels of geographic complexity.

Metropolitan Map Series/Vicinity Map Series

The metropolitan map series and the vicinity map series provide coverage for the nation's major built-up areas. Those built-up areas falling within a standard metropolitan statistical area are covered by the metropolitan map series. Selected areas outside standard metropolitan statistical areas are covered by the vicinity map series.

The political and statistical information on these maps includes the entire census geographic hierarchy. The political information portrayed includes the following boundaries and names: international, state, county (or county equivalent), county subdivision (minor civil division or census county division), minor civil subdivision (where applicable), place (incorporated place or census designated place), Alaska Native village, and American Indian reservation. Statistical areas represented on 1980 Census Maps include urbanized area, census tract, enumeration district, block (where appropriate), and identifiers. The predominant scale of the two series is 1 inch represents 1,600 feet. In selected densely settled areas a larger scale of 1 inch represents 800 feet is used; in less densely settled areas a smaller scale of 1 inch represents 3,200 feet is used.

The symbolization for these two series, as well as all other 1980 Census Maps is standard. Varying line patterns, symbols, and screen values provide the mode of symbolization for these predominantly black and white maps. The standard census typographic system is used for selected levels of information.

All maps in the metropolitan map series and vicinity map series were designed and produced entirely by the Census Bureau from base information depicted on United States Geological Survey quadrangle maps. Modern production techniques were used to produce the approximately 10,700 map sheets in these series. A typical map sheet covering roughly 30 square miles measures 14 inches by 24 inches. For selected sheets within the 19 most complex standard metropolitan statistical areas, color area tints were used to aid the map reader in distinguishing intricate corporate boundaries.

Place Map Series and Place and Vicinity Map Series

The next major level of map coverage includes the place map series and the place and vicinity map series. Place maps were designed to provide detailed map coverage for built-up places not covered by the metropolitan map series/vicinity map series. The place and vicinity map series is basically identical except for minor distinctions in coverage. There are approximately 12,000 place maps and 4,200 place and vicinity maps.

Place and vicinity map coverage is used wherever the development of an area extended beyond legally or census defined place limits. They also provide coverage for those places that have large out-parcels of unincorporated land surrounded by the subject place. Where two or more places fall on the same map sheet, place and vicinity map coverage is used.

The place and place and vicinity map series make use of base maps provided primarily by local or state governments. Some unnecessary information was deleted from these base maps and census information was superimposed upon the base. In selected cases, the Census Bureau prepared its own base map using these local maps as source material only.

The use of a variety of base maps for these series necessarily implies a variety of scales and formats, depending upon the source agency. The base map symbolization also varies from map to map. All census information was symbolized using the standard 1980 Decennial Census map typographic and symbolization systems.

County Map Series

The third level of coverage of the 1980 Census Maps is provided by the county map series. This series covers all areas of the United States not covered by either the metropolitan or vicinity map series or the place and place and vicinity map series. There are approximately 6,100 county maps. The county map series was created in a manner similar to the place and place and vicinity map series. Maps from state agencies, usually state highway departments, were used as bases. The scales of these maps were standardized to a scale of 1 inch represents 1 mile. Map format varies depending upon the base map used. The symbolization and typographic systems for information added to the base use the standard 1980 census conventions.

American Indian Reservation Map Series

The final map series within the 1980 Census Map category, the American Indian reservation map series, provides map coverage for selected American Indian reservations. There are approximately 84 map sheets in this series. These sheets are similar to county map series sheets in format and content; the major difference is the exclusive coverage of American Indian reservations.

The two map series which provide indexes for 1980 Census Maps for block-numbered areas will be discussed in the following section.

SUMMARY REFERENCE MAPS

The summary reference map category includes the following major map series: county subdivision, state standard consolidated statistical area/standard metropolitan statistical area outline, urbanized area outline, census tract outline, state index to block-numbered areas, and standard metropolitan statistical area index to block-numbered areas map series.

The county subdivision map series serves as a base for the state standard consolidated statistical area/standard metropolitan statistical area outline map series and for the state index to block-numbered areas map series.

The second distinct set of derivative maps uses the standard metropolitan statistical area index to block-numbered areas map as a base. The urbanized area outline and census tract outline maps are derivative map series.

COUNTY SUBDIVISION MAP SERIES AND DERIVATIVES

The county subdivision map series presents page-size maps for every state, the District of Columbia, Puerto Rico, and other outlying areas within the jurisdiction of the United States. Depending upon the geographical complexity of a state, the information may be presented on one page or, in most cases, is divided into sections appearing on several pages. To aid in using the multi-page state maps, all sections within a state are at the same scale. In total, the 50 states are shown on 220 pages.

In comparison to the 1980 Census Maps, the county subdivision maps are much less detailed and at a much smaller scale. County subdivision map scales fall into a range from 1 inch represents 8 miles to 1 inch represents 100 miles; one-half the states are at scales of 1 inch represents 18 or 20 miles.

The county subdivision map series provides a simplified framework of census geography in an easy-to-use format. The political information within the census hierarchy is retained on these maps, while the lower-level statistical hierarchy has been eliminated. The information portrayed on the county subdivision map series includes the following boundaries and names: international, state, county, county subdivision, minor civil subdivision, and place. Adjacent state boundary ticks and names, and adjacent county boundary ticks within sectionalized states are shown.

The 1:500,000 state map series produced by the United States Geological Survey was selected as the base map for the entire county subdivision series. Census information (e.g., county, minor civil division, census county division, and place boundaries) was obtained from 1980 Census Maps to complete the compilation phase. New artwork was constructed, resulting in this multipurpose map series.

A special version of the county subdivision map series was prepared showing American Indian reservation and Alaska Native village boundaries and names. This information was superimposed, where appropriate, directly onto the county subdivision map described above. These maps will accompany those report series which contain data for American Indian reservations and/or Alaska Native villages.

State Index to Block Numbered Areas Map Series
The county subdivision map series is used, directly as described above, as the base for the state index to block-numbered areas map series. The index information is superimposed upon the county subdivision map base to create this entirely different series.

The state index to block-numbered areas map series was designed and created for use with the block statistics reports which include all 1980 Census Maps with block numbers. The extent of block-numbered area for each state is symbolized, thereby providing a state index. Two different screen values are used to represent area block-numbered as a part of the urbanized area program and area block-numbered beyond the limits of the urbanized area program. In addition, standard metropolitan statistical area boundaries, symbolized as screened bands, allow the map user to determine the proper report series in which to find census block statistics information.

State Standard Consolidated Statistical Area/Standard Metropolitan Statistical Area Outline Map Series

The second map series derived from the county subdivision map series, the state standard consolidated statistical area/standard metropolitan statistical area outline map series is the least complex of the major 1980 census mapping products. It was prepared by reducing the county subdivision base and preparing an entirely new set of artwork showing selected categories of information.

In final form, each state is presented on a single page showing standard consolidated statistical area and standard metropolitan statistical area boundaries and names using solid and screened bands, respectively. Boundaries and names shown include international, state, county, place (of more than 25,000 inhabitants), and any other central city of a standard metropolitan statistical area regardless of size. Places are symbolized with four dot symbols representing four population classes. Adjacent state names and boundary ticks and adjacent county boundary ticks are provided. The scale for each map in this series is based entirely upon the single page format.

STANDARD METROPOLITAN STATISTICAL AREA INDEX TO BLOCK NUMBERED AREAS MAP SERIES AND DERIVATIVES

The second major grouping of derivative maps includes the standard metropolitan statistical area index to block-numbered areas map series, the urbanized area outline map series, and the census tract outline map series. The base common to these three series was originally prepared for the standard metropolitan statistical area index to block-numbered areas map series, and was then adapted for the remaining two.

Standard Metropolitan Statistical Area Index to Block-Numbered Areas Map Series

The original base maps were formatted by individual standard metropolitan statistical areas at artwork scales of 1 inch represents 2, 4, or 8 miles, the predominant scale being 1 inch represents 2 miles. Map sheets range in size from 21 inches by 25 inches to 40 inches by 57 inches. Approximately 350 map sheets were prepared for all 323 standard metropolitan statistical areas determined as a result of the 1980 Decennial Census.

The political information portrayed on the base map for the standard metropolitan statistical area index to block-numbered areas map series includes international, state, county, county subdivision, and place boundaries and names.

The standard metropolitan statistical area index to block-numbered areas map series uses this political base information combined with additional information to provide a detailed index for block-numbered map sheets within standard metropolitan statistical areas.

The information added to the political base includes metropolitan map series sheet limit lines and numbers, and block-numbered area information. Block-numbered areas are symbolized with two different screen values representing area block-numbered as a part of, and beyond the limits of, the urbanized area program.

Census Tract Outline Map Series

The census tract outline map series is based upon the standard metropolitan statistical area index to block-numbered areas map series. Maps are being prepared for 323 standard metropolitan statistical areas, selected areas within the balance of 48 states, and Puerto Rico. In total, approximately 548 map sheets will be prepared.

For the 323 standard metropolitan statistical areas, the actual political base artwork from the standard metropolitan statistical area index to block-numbered areas map series is being used. Census tract boundaries, tract boundary identifiers, and tract numbers are added to this political base to create the census tract outline map.

Political base artwork for the selected areas within the balance of 48 states and Puerto Rico is being created, because the standard metropolitan statistical area index to block-numbered areas map series does not provide coverage for these nonstandard metropolitan statistical areas. The final map, although prepared differently, is identical in design and content to that described above.

For the majority of standard metropolitan statistical areas, parent map scales are identical to those of the standard metropolitan index to block-numbered areas base map sheets. In congested areas, either the entire base map scale was changed to accommodate the level of density, or insets were prepared for selected groups of tracts. For the balance of state areas, the original scale was selected to accommodate each area.

The majority of parent map sheets are at a scale of 1 inch represents 2, 4, or 8 miles. The predominant scale is 1 inch represents 2 miles; in special areas, scales range from 1 inch represents 1/2 mile to 1 inch represents 4 miles depending upon the complexity of information and the density of the area. Inset scales range from 1 inch represents 1/2 mile to 1 inch represents 1 mile.

The format of the census tract outline map series is similar to that of the standard metropolitan statistical area index to block-numbered areas map series; maps are produced for individual standard metropolitan statistical areas. Approximately 14 multisheet standard metropolitan statistical areas were reformatted; match lines between sheets were changed from arbitrary straight lines to county boundaries to avoid splitting tracts. The balance of state areas are formatted by county or groups of counties.

Census tract boundaries are symbolized with a narrow screened band; tract numbers and tract boundary identifiers are solid. The political base names are screened, but the remainder of the political base information (primarily boundaries) is solid. Inset areas on the parent map are indicated with a light area screen.

Urbanized Area Outline Map Series

The second major map series to use the standard metropolitan statistical area index to block-numbered areas map series political base is the urbanized area outline map series. The purpose of this series is to show the extent of all urbanized areas defined as a result of the 1980 Decennial Census.

To show the individual urbanized areas effectively on page-size maps, the base artwork was standardized to a scale of 1 inch represents 4 miles, and reformatted. The majority of the urbanized areas were easily accommodated on page-size maps. However, in those cases where the urbanized area extended beyond a one-page limit, a multisheet format was used.

The actual extent of the urbanized area is portrayed on the political base through the use of three screen values. The three values portray the different components of an urbanized area, including incorporated places, census designated places, and other qualifying areas not falling into the first two categories.

SPECIAL PURPOSE MAPS

Special purpose maps, the final category of maps, are published on an individual basis pending special requests and funding. As of June 1982, the only maps in this category scheduled for production are those to be published in the several United States summary reports, and the Congressional District Data Books for the 98th Congress.

The maps for the United States summary reports are primarily color thematic maps that highlight different aspects of the 1980 Decennial Census results. These thematic maps appear either on two pages, one page, or one-half page, depending upon the topic of the maps.

Maps prepared for the Congressional District Data Books were designed to portray congressional district boundaries for the 98th Congress of the United States. Each state and the District of Columbia are represented on page-size maps. The state standard consolidated statistical area/ standard metropolitan statistical area outline map series artwork was modified and used as a political base for the congressional district maps. Congressional district numbers and boundaries were added, symbolized as solid type and solid heavy lines, respectively. Insets were used where the geography of the area, in combination with the complexity of the district boundary, was too complex to show on the page-size map. The inset area on the parent map is indicated by a light area tint.

SUMMARY

Although the map series discussed in this paper have been presented as independent products and are, in fact, used frequently as independent cartographic products, their intended purpose is part of a much larger Bureau-wide effort. The series were designed to be integral parts of the major printed report and summary tape file series prepared by the Census Bureau. When published in original form, each map series accompanies an appropriate 1980 Decennial Census report. Together they fulfill the data dissemination function of the Bureau, by allowing the data user to focus on a specific level of data within the tables.

The overall function that maps serve for the Census Bureau will not change in the context of the 1990 Decennial Census; maps will provide a geographic framework for the data collection and data dissemination functions of the Bureau. The manner in which this function or goal is accomplished, however, will change dramatically.

The extent and form of the changes will depend upon the activities of the Census Bureau, and more specifically of the Geography Division, in preparation for the 1990 Decennial Census. In the recent past, the Geography Division has undertaken the development of a long-range geographic support plan, which will evolve throughout the decade. The basic premise of the plan is the development of a major computer file, allowing automation of most major geographic support activities.

At the optimum functioning level, this file will provide the ability to generate maps automatically within the framework of a fully integrated geographic system. Inherent in the development of this automated mapping system is the flexibility provided by, and limitations imposed by, any automated mapping system. The flexibility will allow the Census Bureau to reconsider every mapping variable discussed in this paper--map series, format, scale, coverage, symbolization, and content.

Early in the decade, the 1980 Decennial Census mapping products will be evaluated by the users, both from within the Census Bureau, and from the data user community outside the Census Bureau. This evaluation will be used to determine if the maps meet the needs of the users. The results of the evaluation will provide the framework around which 1990 Decennial Census mapping products will be designed. Automation will provide the means by which these changes can be effectively implemented.

DIGITAL MAP GENERALIZATION AND PRODUCTION TECHNIQUES

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BIOGRAPHICAL SKETCH

David D. Selden received his M.S. in cartography from the University of Wisconsin-Madison in 1979. Since graduating, Mr. Selden has operated a freelance mapping business in Albany, N.Y., worked on an interactive graphics highway safety project for the State of New York, and has done cartographic consulting in the Washington, D.C., area. Currently, Mr. Selden is employed as a cartographer for the U.S. Geological Survey in Reston, Virginia, developing techniques for computer-assisted cartography.

Michael A. Domaratz is a cartographer at the U.S. Geological Survey's Eastern Mapping Center in Reston, Va. He is the team leader for the USGS 1:2,000,000-scale digital cartographic collection project and is involved in various digital cartographic data collection, processing, and display activities. Mr. Domaratz received a B.A. degree in geography from the State University of New York at Buffalo.

ABSTRACT

Two evolving aspects of the cartographic process, digital map generalization and procedures for cartographic manipulation of digital data, will be discussed in this paper. The application of digital techniques to cartographic data has greatly facilitated the cartographer's capability to quickly produce maps of various scales and projections. The hierarchical data structure and unique data content of the U.S. Geological Survey's 1:2,000,000-scale data base offer increased flexibility and enhance these cartographic production capabilities. The explicit encoding of major cartographic categories as well as internal category differentiation (for example, rivers, perennial vs. intermittent; federal lands, national parks vs. national forests) permit cartographic display appropriate for particular scale and theme criteria. The actual cartographic portrayal of these digital data, while based on the coding structure, also requires an efficient interfacing of human/software/hardware components. Finally, compliance with high cartographic standards and exploitation of the data base's potential are dependent on the development of effective digital cartographic production methods.

INTRODUCTION

The availability of digital cartographic data bases is creating a demand for accelerated development of automated map production systems. The content, structure, and unique qualities of these data bases are providing new opportunities for efficient and dynamic cartographic applications. Whether or not these opportunities will be fully exploited depends, in great measure, on the development of an appreciation for the intrinsic value of digital cartographic data designed for mapping purposes.

This paper addresses current work in the area of automated production cartography by focusing on the development of a 1:2,000,000-scale digital cartographic data set at the U.S. Geological Survey. An explanation of the rationale behind its unique data organization and a brief description of its elemental features will be presented. An example of how this data has been used to produce a map product will also be delineated.

DIGITAL CARTOGRAPHIC DATA

Theoretical Considerations

One of the major activities performed during the process of map generalization is data selection. In this activity, the cartographer selects the data to be portrayed on the map. The selection process is governed by two factors: the theme of the map and the scale of the map.

The map theme is the primary idea the cartographer is attempting to communicate on the map. This consideration requires the cartographer to select and portray map data that the user will need to comprehend the theme of the map. For example, a map showing the political subdivisions of an area would probably contain a relatively large amount of data representing the boundaries of the subdivisions and a lesser amount of supporting data (roads, streams, etc.) to help orient the map user. On the other hand, a map emphasizing the hydrography of the same area would have a greater amount of hydrographic data and a lesser amount of supporting transportation and boundary data.

The map scale determines the amount of space available for presenting the data. This factor constrains the space in which data may be legibly portrayed and must be considered by the cartographer in the data selection process. For example, a map emphasizing the transportation network at 1:2,000,000 scale can have more transportation data legibly portrayed than a map of the same area at 1:10,000,000 scale.

Implementation

One major goal of the U.S. Geological Survey's 1:2,000,000-scale digital data set is to provide the cartographer the ability to automatically select the proper combination of data for a map after considering the theme and scale of that map. To achieve this goal, the digital cartographic data are encoded with attribute codes that allow the cartographer to select the data to be portrayed on the map. The cartographer enters these selection criteria decisions into a computer, which processes the data set and extracts those features to be portrayed. By encoding the data with the attribute codes, the data selection process is not dependent on the need for special-purpose map generalization software.

Although the data set contains many different overlays of data (political boundaries, boundaries of federally administered lands, roads and trails, railroads, streams, and bodies of water), a common selection scheme is applied to all of them. The basic scheme consists of organizing the attribute codes hierarchically from the "most significant" feature in the overlay to the "least significant" feature in the overlay. Although the specific criteria for ordering the attribute codes vary with each overlay, the basic scheme allows the cartographer to start with a minimum amount of data for an overlay and to gradually increase map content (within the constraints of the coding scheme) until the cartographer has the data needed to support the theme and scale of a particular map.

The attribute codes for the political boundary overlay are organized in the following hierarchy: international boundaries, state boundaries, and city and (or) county boundaries. The scheme starts by considering the United States as an area bounded by international boundaries. This area can be decomposed into 50 constituent state polygons bounded by adjacent state boundaries; these state polygons can be decomposed into their constituent city and (or) county polygons bounded by adjacent city and (or) county boundaries.

The coding scheme for the federally administered lands overlay is organized differently. The United States is divided into generic polygons which represent national forests, national parks, national wildlife refuges, Indian reservations, etc. Each polygon is further classified by a size criteria determined by the longest dimension of the polygon. This scheme allows the cartographer to select the various types of federally administered lands that are to be displayed, and to control the amount of detail for the types of lands selected.

The road and trail coding hierarchy is organized to display different densities of connected networks of highways for the United States. The hierarchy of attribute codes for this overlay starts with major limited-access highways and their connectors (nonlimited access links where gaps appear in the limited-access network) and continues through major U.S. routes, minor U.S. routes, major state routes, paralleling U.S. and State routes, and other roads and trails.

The theory behind the attribute codes for the railroad overlay is similar to the theory for the road and trail overlay. The scheme, which is based on annual tonnage, starts with a connected network of the primary rail routes and their connectors, and gradually increases the density of the network.

The stream attribute code hierarchy is organized by length of drain. The scheme begins with the longest drain for an area, and the density is gradually increased by adding drains of shorter length, while retaining a connected network. The stream segments are also identified as being perennial, intermittent, or canal.

The theory supporting the water body attribute codes is similar to the theory of the federally administered lands overlay. The categories of perennial and intermittent lakes, marsh/swamps, dry lakes, and glaciers are subdivided by length-at-longest-dimension criteria. The cartographer may select among the different types of water bodies to be displayed, as well as control the density of water bodies chosen.

The limitations of map theme and map scale are important considerations in the data-selection process of map generalization. Using the criteria encoded in the 1:2,000,000-scale digital cartographic data, the cartographer has the much-needed versatility to generate maps by digital techniques.

CARTOGRAPHIC PRODUCTION

During the past year the U.S. Geological Survey has been experimenting with various procedures for applying the 1:2,000,000-scale digital cartographic data set. One such effort has concentrated on using the data with computer-assisted techniques to produce a facsimile of a general reference sheet from The National Atlas of the United States of America. The techniques utilized in this effort and some of their strengths and weaknesses are described below.

Planning

Planning for the (re)production of the general reference sheet required compliance with communication objectives established prior to its original construction in 1966. These objectives included the portrayal of appropriate geographic/cultural features for a region of the United States at a scale of 1:2,000,000. Unique to this planning process were concerns about the adaptability of the digital data to computer techniques. Such concern was justifiable, based on the knowledge that no known cartographic production system had been developed which fully automated the making of a map.

Design

Cartographic design is the process of graphically transforming data and ideas into map symbols and arranging them effectively to promote successful communication. Traditionally, this activity required imagination, a good understanding of accepted symbology, and a trust in the manual skills of the mapmaker. Even though design specifications for the National Atlas reference sheet already existed, the limitations of automated cartographic techniques required new design assessments. The ability of computer-assisted production methods to implement the design specifications had to be determined. Specifically, data symbolization, the placement and availability of high-quality type, and the automatic creation of open-window negatives were only some of the major areas of concern.

An appraisal of automated capabilities resulted in the revamping of certain previous design assumptions in order to maximize the utilization of computer techniques. A decision not to display type was made near the outset. Although the placement of type could have been accomplished using interactive graphic techniques, this was still considered to be essentially a manual procedure. Line and area symbolization was possible by automated means and standards for their specifications were considered of primary concern. In order to produce a final color proof, which necessitated the creation of open-window negatives, a combination of automated and manual methods was utilized.

The design activity also included the identification of appropriate tools (hardware), the selection of techniques (software and human interactive graphics), and the efficient interfacing of these hardware-software components. Three main pieces of hardware were chosen: a medium-sized mainframe computer which utilized an automated mapping software package to transform and symbolize data; a minicomputer with interactive graphics software for layout, editing, and some minor textual information placement; and a flatbed photoplotter for the plotting of color separates. In addition, appropriate software was selected to link the hardware devices.

Compilation

The recent availability of a cartographic data source in digital form changed the emphasis of the compilation activity. Unlike traditional map compilation where source materials are gathered, scaled, edited, and coded for intended graphic manipulation, the results of most of this activity were already provided. In one sense the 1:2,000,000-scale digital cartographic data base was a compiled source "manuscript."

Compilation thus took on a new form. Instead of collecting source information, a great proportion of the activity focused on the study of data format, structure, and basic definitions. Symbolization and color separation schemes were then devised by grouping the appropriate ranges of attribute codes together. The final step in this phase was the conversion of the digital data to latitude/longitude equivalents compatible with the mainframe symbolization software because the original digitized cartographic data resided in on-line disk storage on a mini-computer in X, Y format.

Finishing

Traditional map finishing concerns the creation of final map artwork. Drafting (or scribing), type and symbol stickup, and final layout of the map components represent the major tasks involved in map finishing. Computer-assisted map finishing utilizing the 1:2,000,000-scale digital cartographic data to re-create a National Atlas reference sheet consisted of two major steps: digital cartographic data symbolization-processing and automatic plotting.

Symbolization-Processing. In this particular case the data was symbolized on a medium-sized mainframe computer using an automated mapping package. A job stream was written which defined the desired symbolization parameters and the color separation scheme. In batch mode, this software extracted the desired level of data base information, symbolized the data, and wrote output commands on magnetic tape, which was used to drive a flat-bed photoplotter. Line-weight selection and various symbolizations (for example, railroad, canal, reefs, etc.) were supported. In addition, commands for the plotting of special symbols were available.

An alternative symbolization method which is currently under development utilizes the graphics capability of an interactive graphics system. Once these capabilities are upgraded to match or supersede those described above, a shift in the production flow would be possible. This shift would be advantageous in terms of bypassing the need to convert the original data source to geographic equivalents for compatibility with batch-symbolization processing. A considerable amount of time and effort would be saved. The only advantage remaining to the batch software would be the ability to transform the data into any one of 18 different map projections. This capability is not immediately planned for the interactive graphics facility.

The quality resulting from either symbolization technique, in terms of consistency and maintenance of USGS specifications, is lacking. Judged on merit alone, current symbolization quality is marginally acceptable. Different types of symbolization are distinguishable, although limited and unsophisticated. For the present, development efforts will be directed at expanding symbolization vocabulary as well as streamlining the procedures for their production. However, the amount of software development required to reach these goals of higher standards and expanded capabilities must not be underestimated.

Automatic Plotting

The automatic plotting of symbolized data was accomplished on a flatbed photoplotter. Both positive and negative film separates can be produced as well as scribecoats and pen drawings. Once a secure system of pin registration was established, a decision was made to plot film negatives. Film was punched prior to plotting, and pins were firmly attached to the plotting table. Precautions taken during plotting maintained registration within the approximate 0.003" accuracy specifications of the plotter. Given this reliable registration system, separation plotting in negative increased production efficiency by not requiring the making of contact negatives from plotted positives (much like manual scribing affected drafting).

Reproduction

Once all negatives were processed, they were submitted to a photographic laboratory for the production of peelcoats in the traditional manner. Peeling was done manually to create open-window negatives. The line negatives and open-window peelcoats were then returned to the laboratory for compositing in preparation for proofing and eventual printing. Essentially, the reproduction step remained a purely manual operation. However, some interesting developments are currently underway.

The implementation of raster processing near the end of the production flow could dramatically increase production efficiency. The potential for the elimination of traditional photomechanical reproduction work appears to be attainable, given certain software interface developments. Instead of photoplotting symbolized digital cartographic data, the data would be read directly into an interactive raster color-editing system. Interactive manipulation of the raster files would create the color specifications. Screened and composited negative separates would then be plotted on a laser plotter. These plots would be submitted to a photographic laboratory for proofing and (or) the generation of printing plates.

A Final Product

Certain impressions come immediately to mind when viewing a color proof of the National Atlas reference sheet produced by the methods described. The lack of type, route shields, point symbols, and any geographic/cultural information surrounding the mapped area stands out. The absence of map type has already been addressed in the design section. At this point it is sufficient to say that name/symbol placement is the most complex of cartographic activities, particularly in terms of automation. The lack of map information surrounding the States of Arizona and New Mexico is attributable to the current format of the 1:2,000,000-scale digital cartographic files. They were originally digitized in regions that were usually clipped along state political boundaries.

Even though it is certainly possible to present the data according to the established National Atlas reference sheet format, this does require a considerable amount of additional work at the present time.

On the positive side, some achievements are worthy of note. A symbolized (line weight and pattern) hierarchy of transportation, hydrography, and political boundaries is clearly portrayed. The line negatives which produced the open-window negatives were plotted automatically. The time required to produce the color separations for this map was much less than would normally have been required to produce the same product using traditional manual techniques. In general, a feel for the geographic/cultural features which make up this region can be quickly derived from the map in its present form, thus fulfilling its basic communication objective.

CONCLUSIONS

The availability of a digital cartographic data base, designed with built-in graphical flexibility, and the development of computer-assisted techniques have greatly influenced the character of the map production flow. Such production, as it is presently configured, results from a fusion of manual, photomechanical, interactive graphics, and digital techniques. It is hoped that as a truly automated map production system emerges, new efficiencies unattainable by traditional cartographic means will be realized, and the ultimate goals of efficient production and effective map communication will be better served.

AN ADAPTIVE GRID CONTOURING ALGORITHM

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ABSTRACT

A new algorithm for contouring Digital Terrain Models is presented. This algorithm adapts itself to the terrain so that the number of points required to represent a contour is a function of the roughness of the local terrain and the degree of smoothness requested by the user.

This algorithm avoids two of the most noticeable difficulties encountered in using conventional contouring algorithms, the generating of more points than are required by the terrain, thus using extra computer resources, and the generating of too few, thus creating angular and visually unpleasing contours.

INTRODUCTION

Grid-to-contour (GTOC) is the name of a new computer program developed for Defense Mapping Agency (DMA) which interpolated elevation contours from digital terrain models (DTM). The algorithms used by this program differ from conventional contouring algorithmns in that it adaptively determines the number of digitized contour points required to adequately represent contours as smooth curves when the points are connected by line segments. It avoids two of the most noticeable difficulties encountered in using conventional algorithms; the generation of more points than are required by the terrain, therefore using extra computer resources, and the generation of too few points creating angular and visually unpleasing contours.

DMA has other contour generation programs. They are confined to the mainframe computing systems and are used primarily for data verification and evaluation. The technology and design of GTOC will enable DMA to use the program on many of the mini-computer based systems currently online or planned for DMA. Also, the quality of output suggests the program will be useful in future map production plans for DMA.

A description of the logic and major algorithms used in GTOC are provided in the following sections. Several test outputs based on DTMS are provided as examples of the program outputs.

BACKGROUND

The general contouring problem is to establish all points (x,y) which satisfy the equation

$$E(x,y) - C = 0 \qquad (1)$$

where E represents the elevation as it varies with x and y and C is the contour value.

Cartographers "solve" this equation using a variety of tools, logic, and experience. Their tools range from simple geometric dividers to complex analog photogrammetry systems.

Various digital systems used by the government require elevation data in a form that is easy to handle while maintaining high accuracy. This requirement is satisfied by digital terrain models which are matrices of elevation values.

Although cartographers could apply their classical contouring methods to the tabulated elevations in a DTM, this is unrealistic because of the volume of data and the rate at which DTM's can be produced. Hence computer contouring is a reasonable alternative.

In its simpliest form, computer contouring is a process of connecting dots. If a contour level lies between two DTM values, then the crossing point is on the grid line connecting the values. Other dots can be positioned on grid lines where this contour crosses. Finally, the contour curve can be drawn by connecting the dots with short line segments or curves.

The accuracy and acceptability of contours produced by this simple process depend on several factors. These are

1. accuracy of the DTM values,
2. spacing between DTM values,
3. texture of the area covered by the DTM,
4. procedure for computing dot locations, and
5. procedures for connecting the dots.

Only Factors 4 and 5 are within the control of the contouring logic described above. It assumes that the DTM data are accurate and properly spaced for the topography it represents. Indeed, Factors 4 and 5 are the reasons why computer contouring is not as simple as suggested in the discussion above. There are a variety of techniques for each. Several were investigated and the most effective combination implemented for DMA. These are discussed in the next sections.

CONTOUR PROCESSING

Contour processing starts with a contour level C, initially the first level of interest. Then, a systematic search of the cells is started to locate a cell containing the curve. The search commences at the upper left corner of the matrix and scans down and across. When a curve at level C is detected, points on the curve through the cell are computed as described below. Since the initial cell shares an edge with a cell which also contains the curve, it is possible to move left, right, up, or down in a predictable manner from one cell to the next along the path of the curve. Each time a new cell's elevation values are retrieved from the matrix, points along the curve are computed and added to a string representing the contour.

Tracing the curve from cell-to-cell stops when the last cell processed is on the edge of the matrix (contour exits on a side of the map) or when the next new cell is the same as the initial cell (the curve is closed within the map).

After the curve-tracing stops, the next curve (if any) at level C is sought. The searching starts in the cell just beyond the one where the last curve was initially detected. Searching continues until another curve is located which means that the curve-following logic is evoked again or until the last grid cell in the matrix is analyzed. The entire process repeats for the next contour value or terminates if there are no more contours.

To prevent the detection of a single curve more than once, a logic matrix is constructed. The matrix contains two "YES-NO" flags per grid cell representing the top and left sides of the cell area. Initially, for each contour level, all flags are set to "NO". As a contour is traced through a cell and found to cross the top side, the top flag is changed to "YES". Similarly the left side flag is changed to "YES" if it crosses the left side of the cell. Therefore, all cell areas where the curve intersects the top or left edges will be marked as having been processed. Later when such a cell is checked by the curve detection algorithm, it will be ignored so that the curve will not be retraced a second, third, etc. times. A new curve will be started only if the top or left side flags are "NO". Even if a contour is traced through both the left side and top of a cell, this logic does not prevent a second contour of the same level from crossing the cell since it can be picked up in some other cell and then eventually traced through this one.

As the contour strings are generated, they are transferred directly to disc storage for later processing (display, editing, etc.). The strings are automatically ordered by virtue of the tracing process.

INTERPOLATING CONTOUR POINTS

When the area of a grid cell is very small at map scale, contours can probably be drawn satisfactorily by connecting the points on the cell sides with line segments. However, when the cells are fairly large, it will be necessary to interpolate intermediate points through the cell to produce smooth and realistic contours. The techniques used to locate points along a contour within a cell are described here.

To accommodate both requirements, i.e., defining curves by edge intersections (2 points) alone or by multiple points across each cell, two levels of complexity are required. Ideally the simpliest requirement would be satisfied by Linear Fitting in which the contour intersections with the cell edges are joined by a single straight line. However, since some cells have more than two crossings of a contour level with cell edges, a further refinement is required to prevent ambiguities. Thus for this case a pattern of four triangles is created, each triangle defined by a cell side and the center of the cell. The interpolation is in fact linear over these triangles.

Non-Linear Fitting yields two points where the curve intersects the cell edges plus one or more intermediate points across the cell. When these are closely spaced and connected by straight line segments, the results appear to be a smooth curve through the cell.

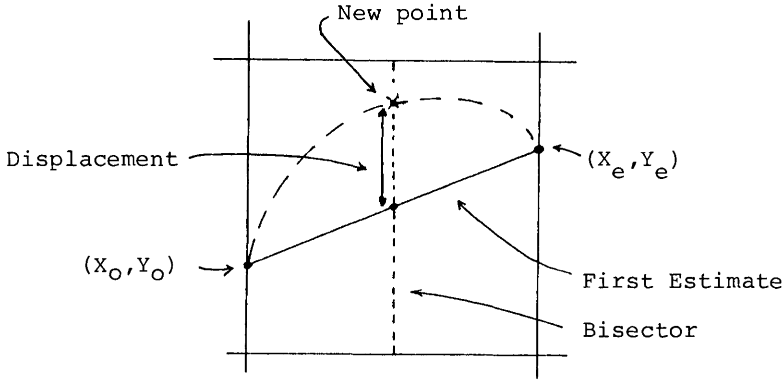
Non-Linear Fitting is much more complex and time-consuming since a local elevation model must be constructed across the grid cell. This model is formulated from 16 elevation values which are at the corners of a 4x4 sub-matrix containing the grid cell at its center.

Two algorithms, called the Adaptive and Stepping Methods, were developed to trace contours across the local elevation models. The Adaptive Method is used whenever possible while the Stepping Method is used only when the Adaptive Method fails.

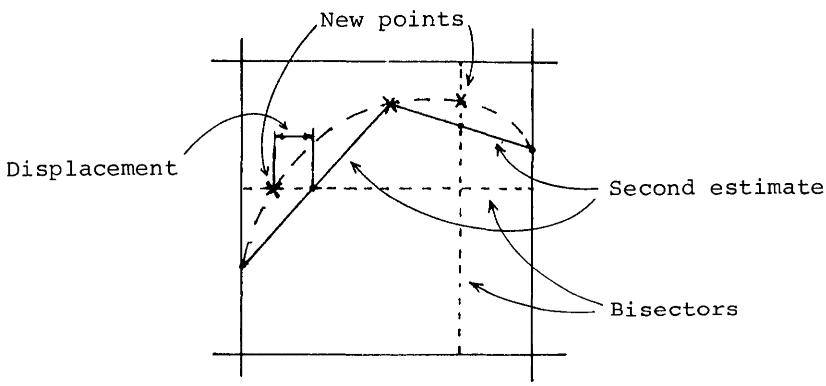
The Adaptive Method starts with the two curve intersections with the cell sides. These are connected by a straight line segment as shown in Figure 1, step 1 where the two curve intersections have coordinates (x_e,y_e) and (x_o,y_o). To decide which additional points are required, the line is bisected to establish a reference point (x,y). Then a vertical or horizontal line is constructed through (x,y) with the line drawn so as to cut the coordinate corresponding to the largest of the two differences $|x_e-x_o|$ and $|y_e-y_o|$. The intersection of the line with the contour is computed by means of interpolation from the local elevation model. The addition of the new point to the original two means the contour can now be drawn with two connected line segments. If the distance from the reference point to the new point is large relative to the cell's width, then the two new line segments can be further bisected to develop 5 points along the curve. This last process is shown in Figure 1, step 2. New line segments are added until the distance from a reference to its new point is "small". Typically, 3 to 5 points are generated; however, up to 50 could be generated if necessary.

The user controls the number of points generated in each cell by defining the fraction of a cell size used to decide whether the distance between the new point the reference point is "small". Very roughly this tolerance parameter corresponds to a potential refinement of the input grid to an overlayed subgrid with dimensions corresponding to the value of the parameter. In other words if the tolerance is choosen to be 0.25 then the resulting contours should be similar in appearance to those obtained by contouring a DTM with 4 times as many rows and columns covering the same area. Of course, the difference is that the intermediate points would be created with this new algorithm only if required by the terrain.

The Adaptive Method does not work for all cells. One problem is created by saddles in which the contour crosses all 4 sides of a cell, making the correct exit difficult to determine. In this and other difficult cases, the Stepping Method is used.



Step 1. The first estimate is bisected. The curve intersects the bisector at the new point. The displacement from the first estimate to the curve is shown.



Step 2. The second estimate line segments are bisected and curve intersections computed to obtain two new points. The curve may now be drawn with four line segments.

Figure 1. The Adaptive Method

The Stepping Method traces the contour by taking very small steps along the curve. It starts at an edge point on the curve and then computes elevation values using the local model at the corners of sub-cells. The curve's intersection with the sub-cell grid lines is computed by inverse linear interpolation. Since a curve enters and exits each sub-cell along its path, it is necessary to compute local elevation values for only those sub-cells. When the sub-cells are very small, the algorithm can follow the most complex curve shapes across the cell. Sub-cells may be as small as 1/256 the area of a DTM cell. From 15 to 30 points per cell are typically generated by this method.

The Stepping Method is more time-consuming since the local elevation model is evaluated more times and more points must be computed across the cell. It does not have the freedom to compute only those points necessary to adequately describe the contour. Consequently, for efficiency it is used only when the faster Adaptive Method fails.

DEFINITION OF THE LOCAL ELEVATION MODEL

The contouring method discussed above requires a mathematical representation E(x,y) of the elevation over each grid cell. Moreover, that equation must be simple to solve in both the formulation

$$E(x,y_f) - C = 0 \qquad (2)$$

where y is held fixed and

$$E(x_f,y) - C = 0 \qquad (3)$$

where x is held fixed. In the approach used here, the elevation is locally approximated using 16 adjacent DTM grid values.

These 16 values are obtained from the 4x4 subgrid centered on the current grid cell. This 4x4 subgrid can be partitioned into four 3x3 subgrids, all of which have the center cell in common. A quadratic fit can be made to each of the 3x3 subgrids to produce 4 separate approximations to the elevation over the common center grid cell. These are called $E_1(x,y)$ through $E_4(x,y)$. To produce a composite E(x,y) the four approximations are weighted and averaged using the formula:

$$E(x,y) = \sum w_i(x,y)E_i(x,y) / \sum w_i(x,y) \qquad (4)$$

The weighting function along with this method of obtaining a final estimate is adapted from work done by Jancaitis and Junkins (1973). As the weighting formula is third order, E(x,y) is actually a fifth order polynomial in both x and y. Since solving Equations 2 or 3 directly would be somewhat time-consuming, a further approximation is made. A lattice is defined of the cell being processed with the refinement of the lattice corresponding to the size of the tolerance parameter defined for the Adaptive Contouring Method. E is evaluated at the lattice points as required and further refinement between those points is done by linear interpolation.

EXAMPLE RUNS

Figure 2 presents the results of applying this algorithm to a 20 x 20 DTM. Sixteen contour levels are shown at a separation of 4 feet. A total of 2205 points are used to represent the contours with the tolerance parameter set to 0.25.

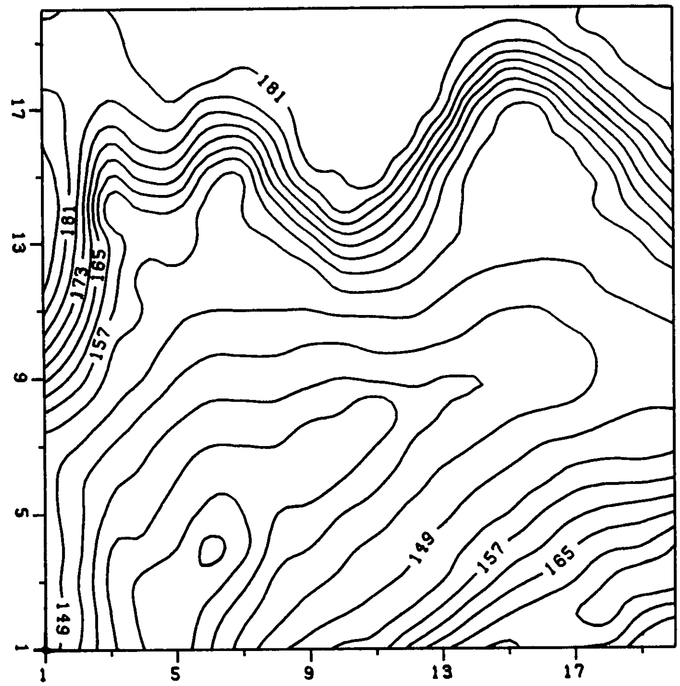


Figure 2. 20x20 DTM, Tolerance = 0.25 - 2205 Contour Points

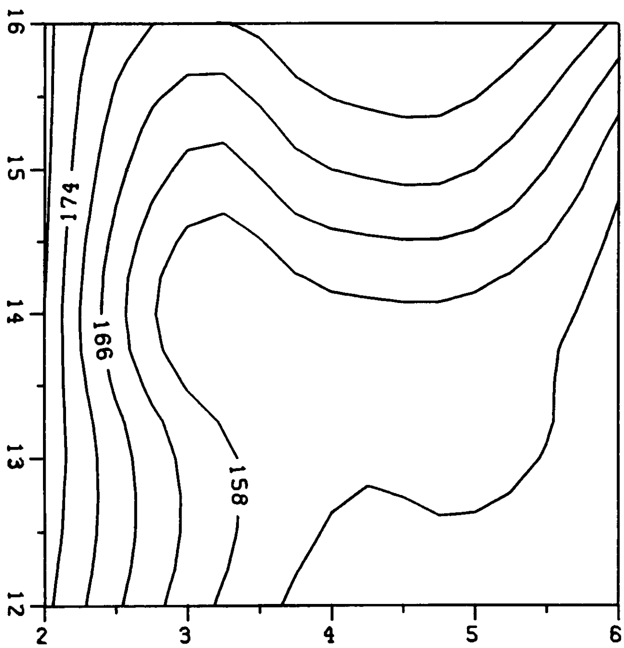


Figure 3. 5x5 Subgrid from Figure 2
Tolerance = 0.25
179 Contour Points

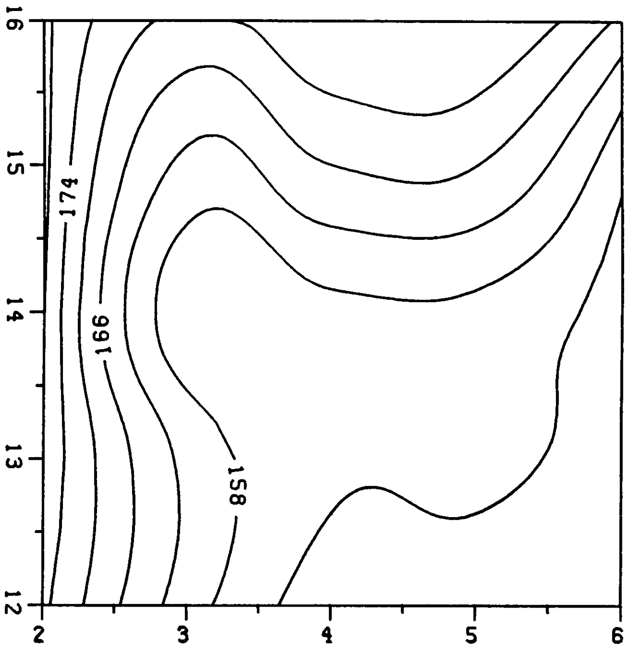


Figure 4. 5x5 Subgrid from Figure 3
Tolerance = 0.0625
665 Contour Points

At the scale shown there would be little improvement in moving to a smaller setting.

A look at a small sub grid in the upper left corner drawn at a different scale shows the effects of varying the tolerance. Figures 3 and 4 are created using tolerances of 0.25 and 0.0625. They require 179 and 665 digitized points respectively. The contours in Figure 4 are noticeably less angular and more pleasing to the eye.

ACKNOWLEDGEMENT

The development of this algorithm was supported by Contract DAAK70-80-C-0248 with the U.S. Army Engineer Topographic Laboratories and the Defense Mapping Agency Hydrographic/ Topographic Center.

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GRIDS OF ELEVATIONS AND TOPOGRAPHIC MAPS

by

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Abstract

Computer assisted topographic mapping is usually based on a DTM in the form of a regular grid. Grids of elevations can be formed in different ways, which may lead to variations in the map being produced. It is therefore important to select an approach to the grid arrangement which provides an adequate terrain representation.

Selecting the desired method of the grid formation is related to several problems: orientation of the grid, density of the grid, combining the grid with separately measured break-lines and modes of acquiring the topographic data.

The problems mentioned above are considered in the paper. Examples produced on the basis of various grids illustrate the discussion.

General Remarks

The topographic data base, known as DTM or DEM, is an issue under discussion for nearly 20 years. Interpolation techniques, arrangement modes and data acquisition procedures have been discussed in journals and symposia. The reasons for the ongoing occupation with the topic are firstly its practical value, secondly its nature - everything stated on the subject lies in the category of an opinion, and whenever opinions contradict one another one cannot logically prove which is right or wrong.

The authors believe that adding their own opinion on the matter may elucidate some aspects which may have escaped the attention of others.

Everybody may agree that a topographic data base aims to represent the terrain numerically. This may sound plausible, nevertheless a clarification of the statement is in order, for it is not self evident what a numerical terrain representation means.

Obviously, everyone would like to have a topographic data base which provides the best representation of the terrain. But that is only an idea, because such a data base should consist of an infinite number of points located with an absolute accuracy. From a practical point of view, when terrain is described by a finite number of points, it has been claimed that the best terrain representation is achieved if all the salient or characteristic points are located during the terrain survey. However, such a statement is not satisfactory because of the vague definition of the term "characteristic point". It is usually said, that wherever a change in the slope of terrain takes place there is a characteristic point. Two objections may be raised here; it is not known what change in slope should occur in order to regard the respective point as being "characteristic", changes in slopes usually do not occur along distinctly and uniquely defined lines (except for man made features), but rather within certain regions. Selecting characteristic points is therefore a result of a judgement, and since there is no basis to expect that every person will have the same point of view regarding positions of characteristic points, each one may locate them differently.

Considering what has been said above, it is seen that topographic data sets, all comprising an equal number of picked up points and including all which is considered as being characteristic points, inevitably differ from each other on the one hand, and must be regarded topographically equivalent on the other. Referring to what has been maintained previously, each such data set ought to be called a best terrain description, which is unsound, for the best must be unique. Hence, even from a practical point of view there is no such thing as a best terrain representation, and we have to conclude that we can speak only about an adequate terrain description. We may say that a topographic data base provides an adequate terrain representation if it meets the accuracy requirements imposed by the tasks for which the data have been collected.

If that statement is accepted, it becomes irrelevant which techniques and procedures are employed as long as the resulting DTM or DEM describes the terrain adequately. The preference of one method over another now becomes a matter of convenience concerning collecting, processing, storing, updating, retrieving data and so on. In such a case it is indisputable that a DTM in the form of a rectangular grid is the one to be preferred.

Topographic data differ in several respects from other geodetic data.

A geodetic point (triangulation point, traverse point, bench mark) is defined only quantitatively by coordinates and elevation. A topographic point frequently carries also qualitative information (e.g. when the point is one of a string describing a topographic feature), and if qualitative information is considered, it is apparent that no mathematical manipulation can provide it adequately.

A geodetic point represents only itself, besides, it is always a subject of direct application (for example, a line of levels is tied to bench marks, or a trig point is the starting point of a traverse, so we are interested directly in the coordinates and elevations of those points). A topographic point, on the contrary, represents not only its location, but also a terrain portion in its immediate surroundings, besides, the potential user of a DTM is rarely interested in a grid corner as such, he is more concerned with points or lines (contours, profiles) derived from the grid points and located in between them.

An additional question concerning the regular grid of the DTM is the density of the data and the method of its acquisition.

Topographic data are usually collected from photogrammetric models in two ways - by scanning the model in a grid mode, or in a profile mode.

Scanning in a grid mode has its advantages since it saves computational effort. It has also been stated that it provides more accurate results. However, that method has its disadvantages too, which follow from the enforcement to carry out height measurements at predefined locations (grid corners). On many occasions, such a location may not be appropriate for a height determination, either because of a local irregularity (e.g. a top of a tree) which distorts the representation of the terrain portion around the grid corner, or because of unsuitable measuring conditions (shadow for example). Moreover, it usually leads to to excessive measuring operations by imposing height determinations at points which do not contribute to the terrain description. Scanning the model in profiles eliminates the above disadvantages, it enables to locate points which are most relevant to the shape of the terrain and it usually reduces also the volume of the acquired data.

The numerous variations in the terrain forms do not lend themselves to rigid rules, hence the question of how dense a grid should be remains open. From our experience we may cite that a grid with an interval between the grid lines of an order of magnitude of 4-10 mm. at the scale of the final map is adequate, the smaller intervals recommended for small scale maps and the larger intervals for large scale maps.

The above observations give rise to several conclusions.

It is essential to locate all characteristic terrain features, as interpreted by the operator while scanning the model. Since there is no law according to which a feature line has to assume a certain shape, any attempt to produce reliably the shape of the line from data not related directly to it, is doomed to fail, even when the data are distributed densely. Consequently there is no reason to form very dense grids.

It is advisable to scan the photogrammetric model in a profile mode. When forming a regular grid from the profiles, the feature lines - watercourses, watershed lines, brinks etc. - should be regarded as boundary conditions (the same applies to the stage of contouring, if a map is being prepared).

Only when a DTM is composed of a grid combined with data describing features, can an adequate terrain representation be assured.

The quality of a DTM should not be judged solely by the accuracy of the elevations of the grid corners. An essential question is how good does a grid corner represent the terrain portion in its vicinity, hence judging the DTM should be based rather on examining the validity of the derived information (contours, sections etc.).

Results of Tests

Below are presented samples of tests which have been carried out in accordance with the above considerations. The samples relate to a model formed from small scale photographs 1:50000 approximately, taken with an overlap of 70% over an area with varying topography, from which a map at a scale 1:25000 with a contour interval of 10 meters was produced. The tests were performed in a Traster Analytical Plotter (Matra) by an operator with limited experience. The ability of the operator to measure elevations was derived from determining repeatedly heights at 105 points distributed at various locations in the model. These determinations were reiterated four times. The m.s.e. of a single elevation determination derived from the above measurements was 0.7 meters. Histogram nr. 1 shows the distribution of the residuals v_h.

The tests aimed to compare data derived from grids with data acquired directly in the model. The quality of a map can hardly be superior to the quality of the model itself, hence the comparative nature of the tests serves our purpose.

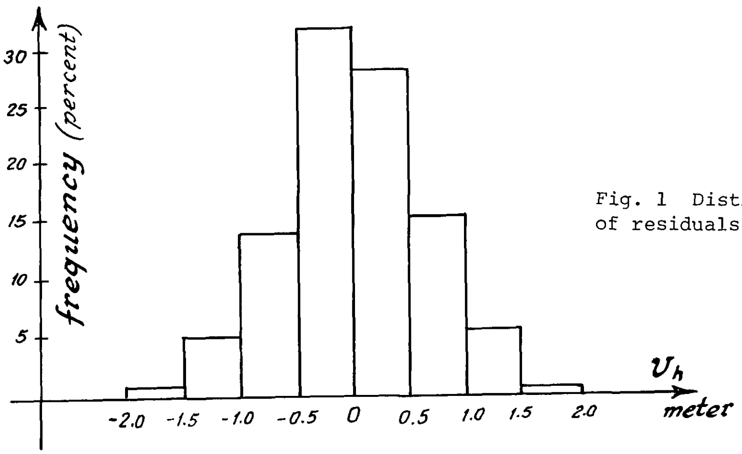


Fig. 1 Distribution of residuals

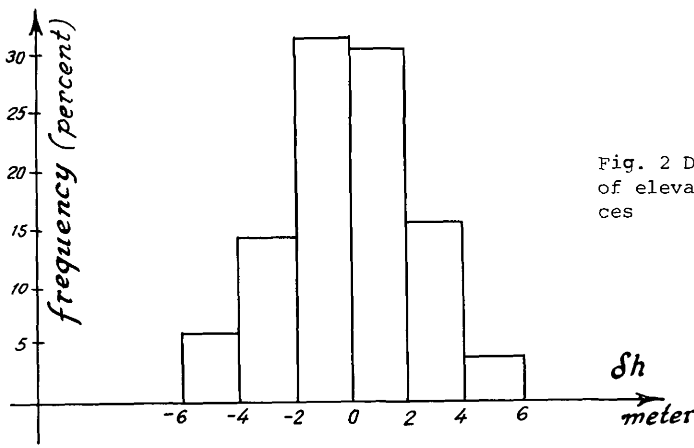


Fig. 2 Distribution of elevation differences

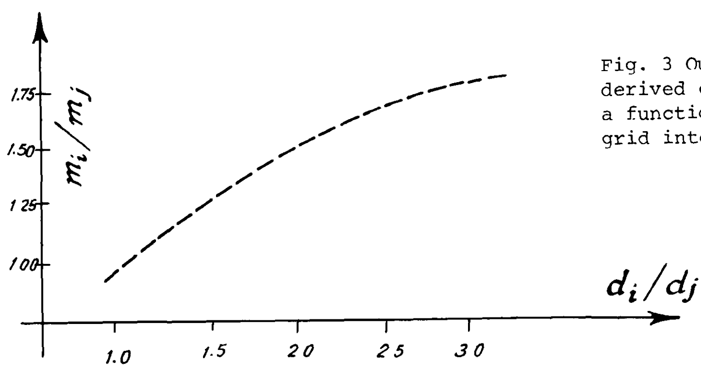


Fig. 3 Quality of derived elevations as a function of the grid interval

In our opinion it is preferable to scan the model in a profile mode. It is usually convenient to scan profiles which are parallel to one of the axes of the instrument (especially in conventional stereoplotters). But a grid of elevations may be oriented arbitrarily with regard to the profiles. It is of interest therefore, to examine whether there is any relation between the orientation of the grid and its quality.

The model was scanned in profiles with an interval of 100 meters between them (4 mm at the scale of the map). Besides, all characteristic features and salient points have been located in the model. Combining the two types of data the following grids have been formed (all with a grid interval of 100 meters):

a: A grid with one family of lines coinciding with the profile lines.

b. A grid parallel to the profiles and shifted with regard to them.

c. A grid rotated by 15° with respect to the direction of the profiles.

d. A grid rotated by 30°.

e. A grid rotated by 45°.

f. A grid rotated by 60°.

From each one of the grids, elevations of about 100 points located variously in the grid squares have been derived by bilinear interpolation. When computing the elevations, all relevant information on the characteristic lines and salient points has been taken into account.

The elevations of the above points have been measured directly in the model. The differences δh between the derived and measured elevations expressed in terms of m.s.e. and extreme values, are summarized in the table below (table 1).

Grid	m.s.e.	min.	max.
	m	m	m
a	2.3	-4.9	4.1
b	2.3	-4.7	5.0
c	2.3	-4.6	4.0
d	2.6	-4.6	4.7
e	2.3	-5.0	4.8
f	2.4	-4.6	4.9

We may also note that in all cases 90% of the differences were smaller than half a contour interval, and none of them exceeded an entire contour interval. It is seen, that the orientation of the grid has no bearing on the quality of the derived information, provided the grids are combined with topographic features.

Histogram nr. 2 represents the distribution of the differences δh.

The model has also been scanned in a grid mode and two grids have been picked up - a grid with an interval of 100 meters, corresponding to the computed grids, and a grid with an interval of 65 meters.

Two cases have been considered here. Elevations of the above mentioned group of points were derived from the "normal" grid (100 meters interval) while combining the heights of the grid corners with the topographic features. Secondly, elevations of those points were computed from the dense grid without taking into account the features. Comparing the results of the above determinations with the elevations measured directly in the model yields:

Normal grid with features -

m.s.e. = 2.2 m , min. = -4.9 m, max. = 4.3 m

Dense grid without features -

m.s.e. = 2.3 m , min. = -4.9 m, max. = 4.9 m

It is also worthwhile to compare the volumes of the acquired data. Assuming that the number of picked up points along the profiles equals 1, the following results are obtained:

Ratio between the profile points and the feature points - 1:1.

Ratio between the grid corners (normal grid) and the feature points 1.2 : 1.

Ratio between the grid corners (dense grid) and the sum of profile points and feature points - 1.4 : 1.

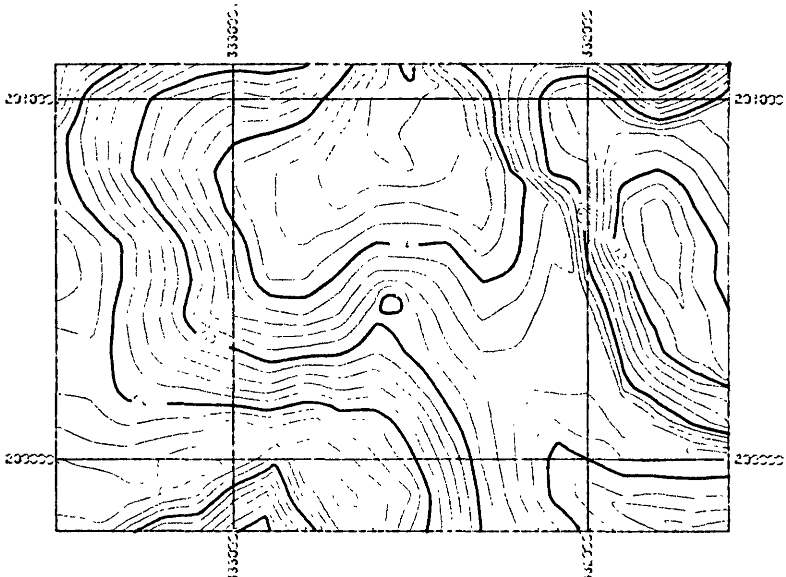
It is seen that there is no significant difference in the quality of the terrain representation as expressed by the various grids, if terrain representation is judged by the quality of elevations derived at discrete points. However, there is a significant difference in the numbers of the measured points. Sparse grids have been formed on the basis of the available data in order to check the effect of extending the grid interval on the quality of the derived elevations. The diagram on figure 3 illustrates the results. On the horizontal axis are plotted the quantities d_i/d_j - the ratios between a grid interval d_i and the intervals d_j. On the vertical axis are given the respective values m_i/m_j - the ratios between the mean square errors of an elevation determination in a grid with an interval d_i , and in a grid with an interval d_j.

The diagram shows a prominent deterioration in the quality of the grid when the grid interval is increasing.

To get exhaustive information on the validity of the terrain models, the tests presented above have been complemented by maps and terrain sections, prepared from a photograph at a scale 1:30000 with a contour interval of 5 meters. Two samples of maps are given in figure 4. The map labelled 1 has been prepared from a grid produced from profiles in combination with topographic features. The map labelled 2 has been generated from a dense grid picked up directly in the model and without taking into account the topographic features.

Map nr. 1 shows sharp changes in slope which occur in regions containing topographic features. That effect is eliminated somewhat on map 2,

Figure 4. Samples of maps



Map 1

Map 2

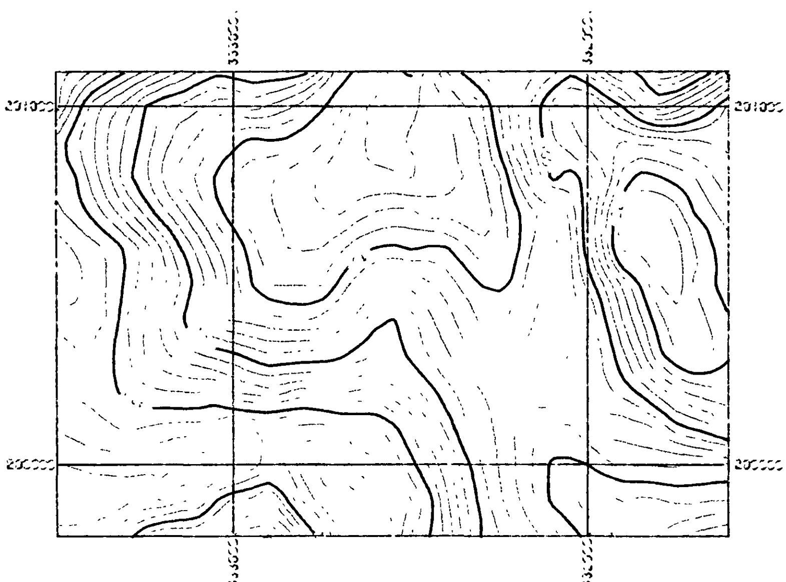
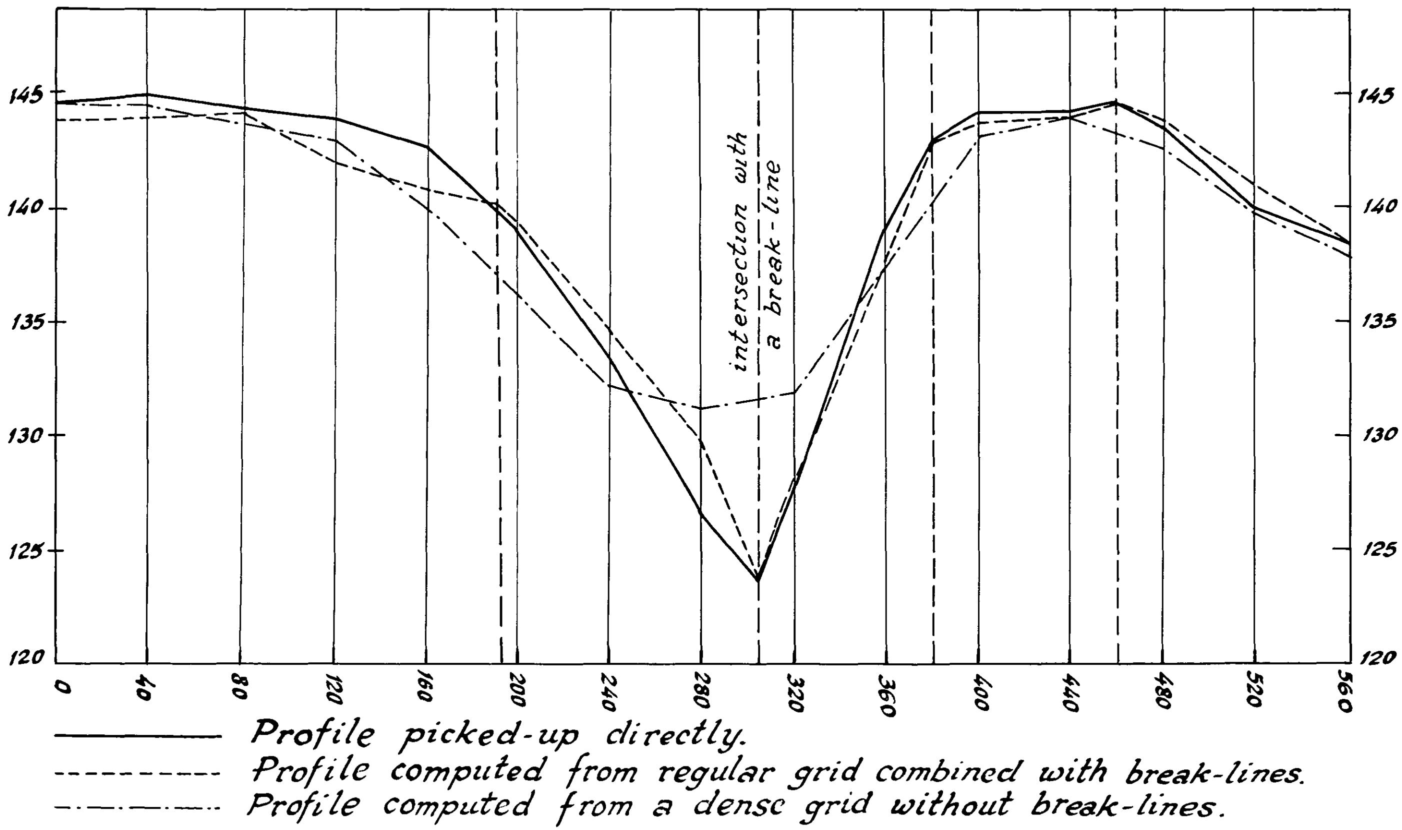


Figure 5



145
140
135
130
125
120
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560
intersection with
a break-line
Profile picked-up directly.
Profile computed from regular grid combined with break-lines.
Profile computed from a dense grid without break-lines.

since there were no boundary conditions imposed on the contour generation. Besides, the contours on map 2 are more noisy, which has to be attributed to the shorter distances between the grid corners.

A number of terrain sections were derived from the data. Each section was formed in three ways: the first was produced from the grid based on profiles and features, the second was determined from a dense grid picked up directly in the model and the third - measured directly. A sample of a section is depicted in figure 5. It shows clearly the agreement between the section derived from the profiles plus the topographic features and that measured directly, and the poor quality of the section derived from the dense grid.

Summary

A topographic data base composed of a regular grid and data describing topographic details represents the terrain adequately.

It is advisable to scan the model in a profile mode. The orientation of the grid produced from the profiles is irrelevant to terrain representation.

It is worth noting that an unskilled operator, after a short training period only, is able to acquire reliably the topographic data necessary for the data base, in contrast with the degree of skill required from an operator who produces maps by conventional procedures.

A COMMUNICATION MODEL FOR THE DESIGN OF A COMPUTER-ASSISTED CARTOGRAPHIC SYSTEM

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ABSTRACT

This paper explores some fundamental considerations for the design of a general, computer-assisted cartographic system. While many researchers have examined how to convey environmental models by means of maps, little is known about the cartographer as percipient of the variety of source used in cartography today or of how that input is transformed into the cartographer's product. The input differs in significant ways from traditional source and from the map the cartographer is making. The paper addresses capabilities which might be used to support a cartographer developing a map or chart using a variety of source materials and computer assistance.

In order to prescribe design options and system capabilities for computer-assisted cartographic systems, we must better understand how a cartographer develops his or her own model of the environment and of the information to be represented, along with the processes she or he uses to transform the model into a product. Such information must inform our specification of retrieval, manipulation, display, storage, and data representation facilities that are needed in computer-assisted cartographic systems and of the ways those capabilities must interact. The paper presents a model for looking at the cartographer at work and discusses considerations for the design of a computer-assisted cartographic system.

INTRODUCTION

Computer technology is changing the cartographer's work environment in several significant ways. Cartographers are making new kinds of products which may be used by other cartographers or by "user systems" such as planning support systems, simulators and automatic piloting devices. As technology enables users to exploit more accurate and precise information, their requirements are becoming more stringent. Cartographers are using new tools in order to respond to such requirements. Computers afford capabilities for making more accurate and precise products as dictated by user requirements. With increasingly demanding currency requirements, we can foresee the time when some classes of maps will require updates based on real-time analysis of new data. Such a requirement will also require perusal of large volumes of source materials in very short times.

Cartographers are employing a widening range of source materials, including such materials as new kinds of soft copy maps and imagery, data bases of textual information, such as surveyors' field notes, and digital data bases of terrain, cultural, and landscape features.

Automated systems are performing many mechanical tasks, such as drawing grids and contour lines, that currently occupy large amounts of the cartographer's time. In addition to allowing the cartographer to focus on product content, such systems have the advantage of permitting cartographers to preview and edit the results prior to plotting. Computers make available means of viewing and manipulating source materials and intermediate products in ways that were heretofore impractical or impossible.

In this paper we address ways of expanding computer assistance to cartographers to support the higher order cognitive activities that a cartographer must perform. Such capabilities will permit development and maintenance of higher quality products with decreased production time.

FOCUS

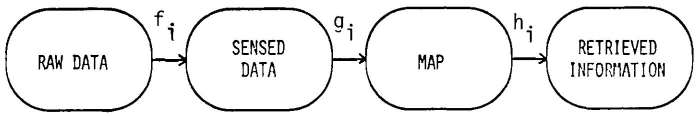
We are interested in the making of reference maps in a production environment in which professional cartographers design new product lines as well as designing and constructing maps to specification. In such an environment a single instance of the production process may result in multiple products or in inputs to multiple products.

We see the cartographic process consisting of two related kinds of mental and physical activities. In this paper we refer to them as the generation and selection of information content, e.g. the name and location of a city, and the portrayal or representation of that content, e.g., the symbol used to locate a city and the typography used for its name. The portrayal part of cartography has been studied in considerable detail. Portrayal consists of selecting the most appropriate means of depicting information as well as of implementing the portrayal of specific facts. In the past, much of the cartographer's craft has consisted of meticulous execution of essentially mechanical actions to depict information. Technology now affords automated support for some of the more mechanical tasks. It affords considerably less for the other part of the cartographer's job, the generation and selection of information and the construction of new knowledge. Such activities are being increasingly recognized as an important part of cartography. Reasons for such a change of emphasis include the relegation of some portrayal tasks to automated systems, increasing demands for completeness and timeliness, increasing volumes of available, often conflicting, source inputs, and the absence of direct experience by the cartographer of the milieu to be portrayed.

We submit that cartography as a discipline is becoming more oriented toward comprehending, evaluating and assimilating information, and synthesizing new knowledge, thus more of a cognitive activity than ever before. As a consequence, we would expect to see changes in the education of future cartographers and changes in the tools available to the cartographer.

MODELS OF CARTOGRAPHY AS COMMUNICATION

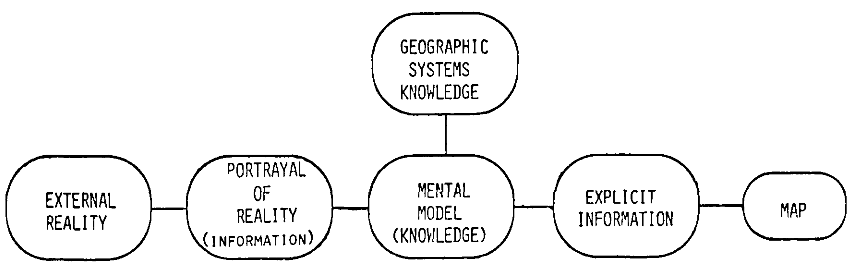
A widely accepted model of the cartographer's system looks something like the one below. (We have adapted this model from Morrison (1978)).



SET D SET S SET M SET R

According to the model the cartographer serves as a mediator between reality and the map user. The cartographer's role in the traditional model is often defined to be that of transmitter of information. We want to explore in greater detail the relationships of sets D, S, M, and functions f_i and g_i.

We propose a model in which nodes correspond to information objects and arcs represent mental or physical processes. The cartographer is the agent directing information flow and the generator of new or transformed information.



The node labelled "External Reality" corresponds to the milieu the cartographer's product is intended to represent. The node labelled "Portrayal of Reality" corresponds to the information available in materials the cartographer uses as input.

The cartographer brings to this task a body of knowledge about systems in the world at large. Cartographers deal with ecological systems, economic systems, transportation systems, drainage systems, cultural systems and many others. In order to evaluate information for correctness and for relevance to the intended use and to determine the optimal portrayal of the information in the final product, cartographers must consider the interdependencies among system components. In this paper we refer to such knowledge as "Geographic Systems Knowledge."

The cartographer's "Mental Model" of the milieu of interest includes an ever-expanding body of "unformulated" or tacit knowledge (Robinson and Petchenik, 1976). Drawing upon the work of Polany and others, they define tacit knowledge as "the nonverbal, non-imaged conception of meaning. . .which is held to be true and known." Such knowledge acts as a transformer and as a filter for all perceptions and externalizations by the cartographer.

The cartographer articulates explicit statements of portions of the mental model, which can be examined, manipulated and revised, either alone or in conjunction with other "Explicit Information". The actions result in an expanded and revised body of tacit knowledge as well as in a growing body of externalized information.

There are various categories of explicit information. They include imprecise information that constitutes a skeleton to which new information is added. It can be made more precise without requiring a major revision of one's tacit knowledge. One example of such information is a rough sketch of the most pronounced geographic features of an area. The second kind of explicit information is information about something that has a relatively broad scope of influence, such as general information about climate or density of population, or changes that have affected a large part of an area, for example, information that was once cultivated is being allowed to revert to wilderness or that an area is recently developed for a particular use. Another kind of explicit knowledge is detail, which is distinguished by its relatively small impact on the total area as known to the percipient.

Finally, we would like to mention the susceptibility to change of an isolated "piece" of information, as another criterion for categorizing explicit knowledge. Susceptibility to change depends upon various things, particularly the source of data and its impact on the percipient's overall sense of the area. Control is a kind of explicit information that is not very susceptible to change, as is information about the general direction of flow of a river. On the other hand, conflicting data that are extracted or derived from different sources are highly susceptible to change and interpretation by the cartographer. In fact, the "revision" of such data to be consistent with less changeable information is a significant part of the cartographer's job. Explicit information may be either spatial or logical-mathematical in character. It may be stored in any number of forms, residing in the cartographer's mind or externalized in any number of ways.

"Map" represents the end products of the cartographer's activity, a subset of the body of the cartographer-generated explicit information. The selection and extraction processes are inevitably influenced by the cartographer's tacit knowledge (Robinson and Petchenik, 1976) as may be all of the activities that result in the portrayal of the information. The portrayal process, however, is outside the scope of this paper.

The model delineates the types of knowledge and information cartographers deal with. Computer systems that store, manipulate, inter-relate, and display such classes of information can be powerful tools for the next generation of cartographers. The benefits cartographers realize from such systems will also depend on the power and appropriateness of the interfaces available to the cartographer.

The processes represented by the arcs in our model, are less well understood than the types of information discussed above; however, there is research on cognition and related subjects which might help us understand the processes involved.

ROLES FOR COMPUTERS

Computers can help cartographers utilize the information and knowledge identified in the model above. We now explore some examples of the assistance computer systems might provide. A better understanding of the mental operations used to construct a mental model and the body of explicit information from which the final product is extracted will no doubt result in definition of operators that have not yet been proposed for automated systems.

The ability of an automated system to portray reality is limited by the kinds of data it can store. There are today a variety of kinds of systems for storing various kinds of digital data, including cellular data, linear data, and character data. Cellular data includes single and multiple related frame imagery and raster-scanned maps,digital elevation data and surrogate travel. Linear data includes digital representations of features, such as roads, rivers, boundaries, with assoicated length and direction. Character data ranges from free form text data bases to highly structured data bases, which may include much descriptive information about data stored in other formats. Most systems in operation today utilize only one of the kinds of data listed above; moreover, the data must be in a system or sensor specific physical schema and in a system-imposed logical schema. More advanced systems will be able to store multiple kinds of data (Hagan, 1982), and perhaps to select and retrieve non-digital data such as microfiche.

The choice of source materials available to the cartographer is limited by our ability to move data from one system to another. Standard data formats and standard data structures enhance the economic feasibility of doing so. The National Committee for Digital Cartographic Data Standards is addressing standards for spatial data. Other standards activities, such as those of ANSI/SPARC and the International Standards Organization are working on other standards issues.

The ability to store data is only useful when the relevant source can be readily identified, selected and retrieved. It is currently too expensive to index source materials manually. Automated indexing capabilities require the ability for the system to derive and encode attributes of imagery and other source materials. Decision aids to support source selection can be extended beyond boolean algebra and text search capabilities to include heuristics. Sophisticated decision support systems that incorporate heuristic search are becoming available to other professional groups and warrant investigation for their applicability to the source selection problem.

The cartographer's mental model consists of both tacit and explicit knowledge. A cartographer constructs a mental model on the basis of his or her own organization and manipulation of various information inputs. A computer assisted cartographic system can make available a variety of operations to view, rearrange, and transform information. The cartographer must be able to use such operations in a manner that fits his own cognitive style. As the cartographer performs different kinds of mental activities at different times during construction of the mental model, he/she may use different kinds of assistance. Construction of the mental model depends upon availability of source materials that are not used for direct transfer of data to a working manuscript. Such materials may present a broader view of the area or a more detailed depiction than the final product.

There is evidence that people tend to form a holistic first impression of anything new before examining details. A cartographer starting production of a large-scale map, for example, may look at a small scale map in order to get a feel for the area. Other capabilities to support construction of the initial mental model included three-dimensional perspective displays, fly-through and other forms of surrogate travel, and rapid sequence projection of user-selected images, such as thirty Landsat scenes over the same area to provide a survey of seasonal changes. (The system must perform transformations so that images are displayed to the same projection and scale.)

As the cartographer proceeds to more detailed analysis of the area other operations might be used, such as overlays of geographic and image material. The system might highlight or suppress information based on various user-specified criteria, which might include operators currently available. For example, a cartographer might wish to highlight or suppress roads that are not cleared of snow.

Technology to support such operations is currently available. For example, flight simulators provide both three-dimensional views and fly-throughs. Image processing systems can identify differences between two images of the same area. Medical experts are using displays of CAT scan data from various perspectives. A deeper understanding of the mental processes used in cartography may uncover the need for new operations and types of displays to support practitioners.

The essence of the cartographer's contribution lies in the identification and representation, directly or indirectly, of numerous relationships within a geographical system. Cartographers are particularly concerned with spatial and geographical relationships; however, they must also use and understand economic and cultural system attributes and their implications. Geographic system knowledge in an automated system can be used in several ways, most notably to identify apparent inconsistencies or anomalies that become evident only upon examination of data in the context of the system under study, to constrain operations initiated by the automated system or by the cartographer, to generate inferences and other kinds of information, to identify new relationships among individual data items, and to solicit information from outside the system.

System knowledge is sometimes made explicit in various forms of rules that are stored and used by computer systems. Researchers in artificial intelligence have implemented a number of systems that store and use system knowledge. Generally, knowledge based systems focus on a rather narrowly defined topic, such as medical diagnosis or molecular structures.

Cartographers draw upon a wide body of general knowledge about the world, rather than upon a specific body of well-defined and detailed information. It is important to be able to define the scope of statements of system knowledge, using a wide range of variables, including historical and geographic factors. Such capabilities would allow the cartographer to have the system invoke statements about a particular area of interest, such as a reminder that the soil composition in the area supports only certain kinds of vegetation, which in imagery looks like other vegetation that is more familiar to the cartographer.

Geographic system knowledge might be most useful to cartographers as a guide and an alerting system in which the system calls the cartographer's attention to potential inconsistencies or gaps in stored information, and the cartographer directs the system on when and how to resolve the conflict. Cartographers might use such capabilities to assist in collecting and compiling the body of interrelated information that is the basis for producing a map. The working cartographer needs to be able to define statements of geographic system knowledge and to delete or modify tentative statements that she or he finds useful to test and examine during the compilation of explicit information. Geographic system rules could also be used to save and make available for later use general statements about a milieu that constitute a part of the cartographer's mental model.

A cartographer's working product is a part of the explicit information in the model above. It can take many forms, ranging from rough sketches which may be discarded to precisely plotted manuscripts. If the working product is stored in an automated system, the cartographer can manipulate and display it quickly. The system can generate displays of the information that cartographers using traditional methods do not have time to prepare.

The cartographer can insert information not already stored in the system and modify stored data using either graphic or alphanumeric representation. Data can be specified on displayed materials, extracted, transformed, and moved into the body of explicit information the cartographer is using. In many cases transferred data consists of one or more pieces of specific information, such as the course of a river. It is desirable to be able to add other kinds of explicit geographic information, including distribution patterns, such as density of certain vegetation of soil types, and generalizations, such as the eventual destination of rivers in an area. The system must also accommodate information concerning portrayal of the data and information about the origin and accuracy of the data and the confidence the cartographer has in it. All of the presentation options mentioned for exploitation of source materials are needed for use with explicit data. In addition, the cartographer needs to work with the data using various projections.

In order to examine and verify or revise the information a cartographer needs to be able to select portions of explicit information on the basis of boolean operations on any of the data stored; in order to exploit the data in the system, a cartographer also needs aggregate operators, spatial operators and operators to apply geographic system rules to specified portions of the data to do such things as identify gaps in the data or inconsistencies of various sorts. Work on the definition of spatial operators is proceeding in this forum and others. Considerable work remains to be done on the use of geographic system rules in conjunction with geographic system data. Such capabilities are need for transforming or deriving data for display as well as for selection.

CONCLUSIONS

The shift of emphasis in cartographers' work should see a corresponding expansion of the information support available in computer assistance. Users of computer assisted cartographic systems need to be able to treat geographic systems as systems, rather than as collections of independent pieces of information. The functionality available in computer-assisted cartographic systems should reflect the mental activities they are intended to support. In order to design more appropriate computer assistance, system designers need a model of the cartographic process that identifies the mental operations involved.

Implemented systems will be unobtrusive aids to cartographers only if they provide the functionality required and an interface appropriate to the user population and to the work environment.

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ANGULAR LIMITS ON SCANNER IMAGERY FOR VEGETATIVE ASSESSMENT

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ABSTRACT

Tracking the condition of field crops by remote observation requires frequent (about weekly or more often) repetition of coverage. Landsat data alone does not provide this frequency of coverage and must be supplemented by other sources of information such as soil moisture models and alarm models driven by meteorological inputs. Satellite systems with a wider scanning capability than that of Landsat or with a pointing capability can provide frequent acquisition. This frequency increase is provided at the expense of spatial resolution and/or consistency in viewing geometry, thereby confounding interpretation of the observed data. As the viewing angle departs from nadir the path length of the signal increases, amplifying atmospheric effects; and the scene content (fraction of soil, vegetation and shadow in the scene) varies. The effects of these phenomena are apparent even over the relatively narrow scan angle of Landsat.

Using NOAA-6 and -7 Advanced Very High Resolution Radiometer (AVHRR) data the magnitude of these effects for wider angles have been considered. The degree to which several existing models can correct for these effects have are being considered along with the sensitivity of various vegetative indices. Practical limits to scan angle for vegetative assessment using current technology are being established.

INTRODUCTION

Tracking the condition of field crops as they respond to their environment requires frequent updates. During critical stages of growth this update may be required as frequently as each week. The Landsat system with an 18 day repeat cycle (assuming no clouds) was not designed specifically for this purpose. It has been used, however, in conjunction with land based information and weather observations, in this manner. The NOAA 6 & 7 AVHRR channels 1 and 2 when ratioed or differenced provide indices related to vegetation cover and/or vigor very much like the indices developed using the Landsat MSS channels. Significant differences in the capability of the two systems exist, however. The AVHRR (designed for cloud monitoring) can provide multiple views daily at a maximum spatial resolution of 1 Km^2 while Landsat with a spatial resolution of 1 acre views once each 18 days. The frequency of AVHRR data comes with a cost. Not only is the resolution less than that of Landsat (This is something that can be accommodated for wide area crop condition monitoring), but the wide scan angles required to obtain frequent observations complicate considerably the analysis problem due to the non-Lambertian nature of the surface effects and, due to atmospheric effects, both of which increase with scan angle. (Fig. 1) The frequency with which scene information can be acquired in the absence of clouds as a function of ability to use off nadir data is:

Full scan width AVHRR ($\pm 56^{\circ}$) provides multiple views daily;
Half scan width AVHRR ($\mp 28^{\circ}$) provides coverage every other day;
Quarter scan width AVHRR ($\pm 14^{\circ}$) provides coverage every 5th day;
Landsat scan width ($\pm 5^{\circ}$) provides coverage every 18 days;

To make full use of the wider scan angle of the AVHRR, procedures must be provided so that comparison can be made between scenes viewed from different illumination and viewing angles.

When techniques to apply AVHRR data to crop condition assessment first became available (Gray, 1961) a decision was made by the principle operational user of the data at the time, USDA-Foreign Agriculture Service, to use quarter scan width, uncorrected, until improvements could be made. This provides 5 day repetitions which could be adequate for their need except for clouds. However, clouds are found to be a significant problem during critical growth periods of many crops and there is a definite need to have the capability to analyze data at intermediate times. The Early Warning Crop Condition Assessment Project in AgRISTARS has, as one of its objectives, the development of procedures that will permit extension of the swath width used.

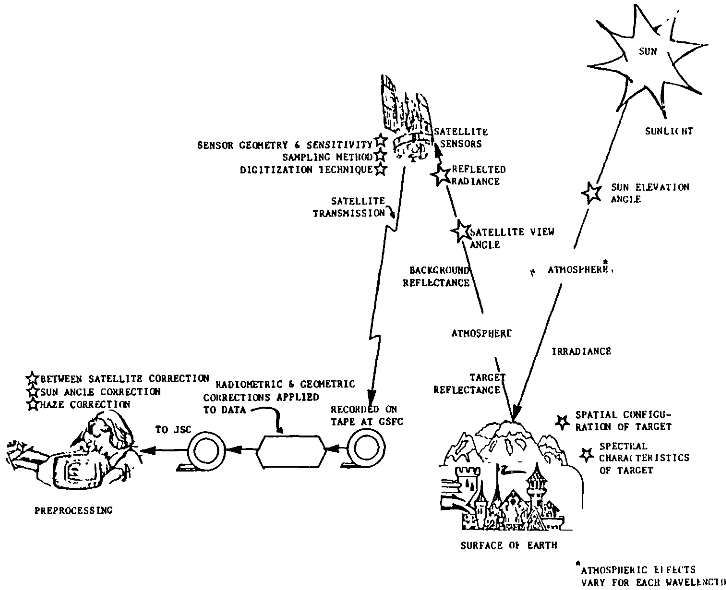


Fig. 1. The Problem

APPROACH

We have chosen to address the problem with a combined simulation modeling and empirical approach. Both canopy reflectance models and atmospheric models are employed. Surface data to support model test and the empirical approach are taken from the LARS archives at Purdue University and from scattered other sources as may be found. Satellite data used is the AVHRR data available to the AgRISTARS Early Warning Project.

The canopy models considered for use to date is that of Suits (1972) and a simpler model developed by Jackson, et al (1979). Atmospheric transfer models selected for consideration are those of Herman (1975) and from Dave (1978).

In the empirical part of the study we have selected full swaths over the U.S. east of the Rockies and averaged 50 scan lines; the resulting "average" scans will be subject to statistical analysis from which seasonal and location specific patterns are expected to emerge. In addition, selected typical sites are selected and the change which occur in signature as a function of viewing geometry, illumination geometry and season, are determined. The empirical portion of the study is intended to provide a family of primitive correction procedures, and guidance in selection of existing models; and should, with time, lead to improved comprehensive models designed specifically for this application.

DISCUSSION OF FINDINGS

Experimental results were obtained from digital data analysis in the following manner. Fifty sequential lines on the Julian dates 187 and 192 in 1981 were selected from the Global Area Coverage (GAC) format of AVHRR, in which four pixels were averaged out of each sequence of five along every third scan line each give a compressed scene value. These GAC values were averaged over the 50 scan lines. Before anlaysis, the data were first screened using bands 1, 2, and 4 (400-700 nanometers, 700-1100 nanometers, and 10-12 microns). These three bands were presented in a false color rendition in order to examine the location of cloud. Particular attention was accorded the presence of popcorn cloud, so that as far as was possible sub pixel sized cloud was avoided. Figures 2 shows that not only do the raw digital radiance values obtained in each of the first 2 AVHRR bands demonstrate an angle dependence, but so does the vegetation index.

$$VIN2 = \frac{AVHRR2-AVHRR1}{AVHRR2+AVHRR1}$$

This form of analysis does suffer from the disadvantage that the target probably varies across the area whose image is analyzed. However, the area was selected for uniformity to minimize this problem and consists of farmland, with a small proportion of forest. In order to further substantiate the angle-dependence of the data shown, like areas were examined from different view angles on sequential days (Fig. 3). The count values are shown plotted against view angle for a mixed forest.

In a somewhat different analysis assorted uniform scenes were selected over a period from Julian day 189 to 194 in 1981. (Fig. 4) In this analysis, counts were normalized to solar zenith so that the pattern of counts as a function of viewing angle is proportioned to the pattern of bi-directional reflectánce. In some cases two views of the same area were acquired. The bi-directional reflectance pattern tends to be similar to that acquired from ground base observation, i.e. reflectance strongest with sun to the back of the observer. For this time of year (mid Oct) the agriculture scenes have little green vegetation remaining and the effects of the non-Lambertian effects of the canopy is suppressed over that taken prior to harvest (Fig. 2). Fig 5 shows the pattern of another form of vegetation index for this collection of views. Again general enhancement of the index occurs near nadir.

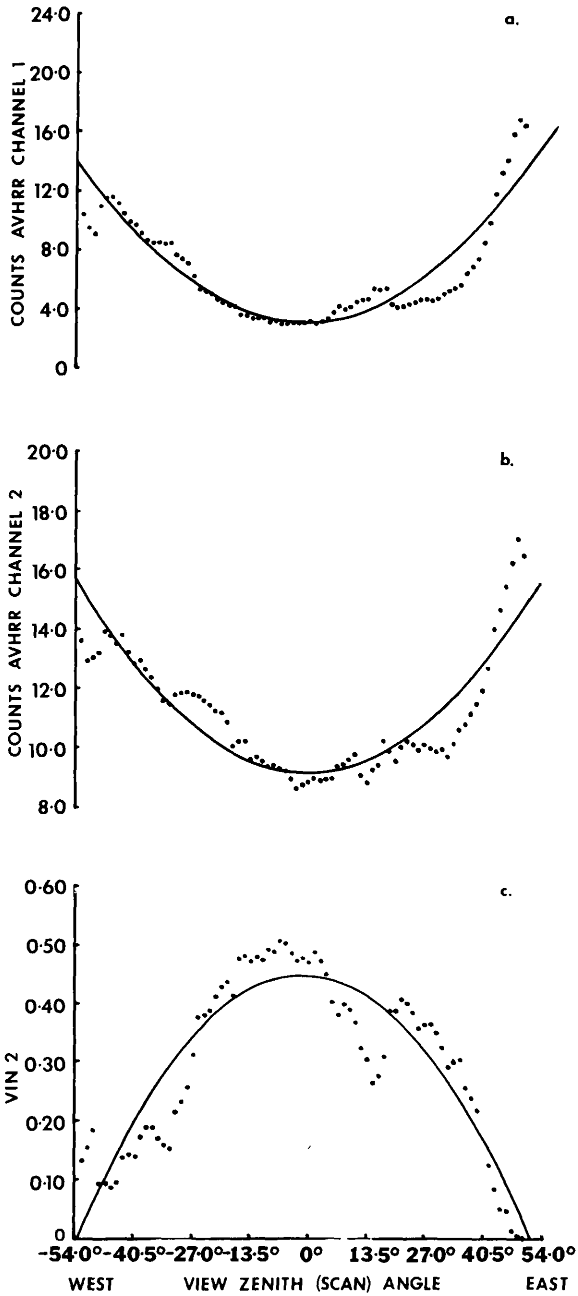


Fig. 2. Average Value over 50 Scan Lines of Channel 1, Channel 2, and Vin 2.

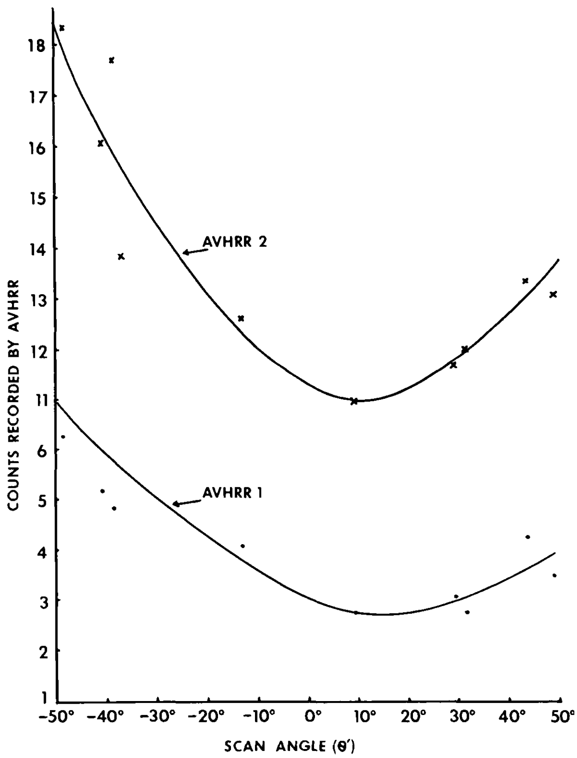


Fig. 3. Areas of Mixed Forest Viewed from Several Angles.

Fig 4. BI-DIRECTIONAL REFLECTANCE FACTOR FOR ASSORTED SCENES.

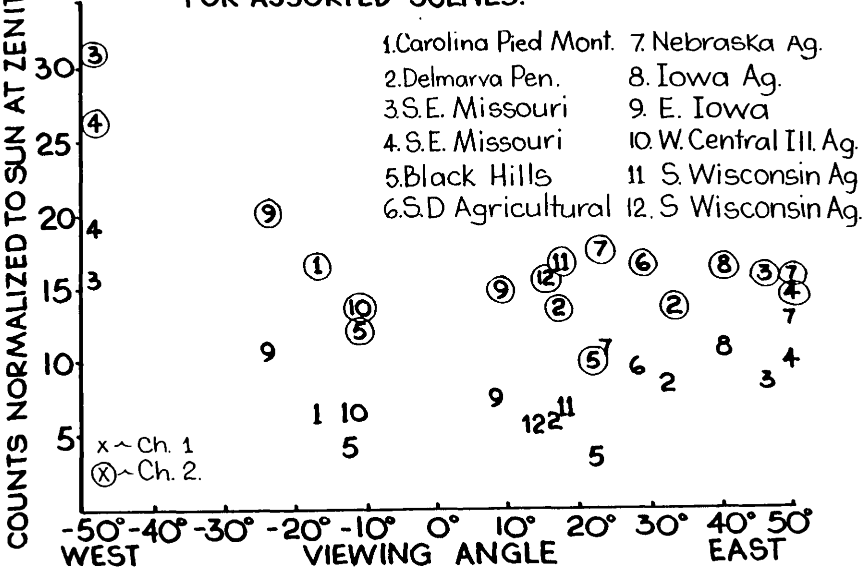
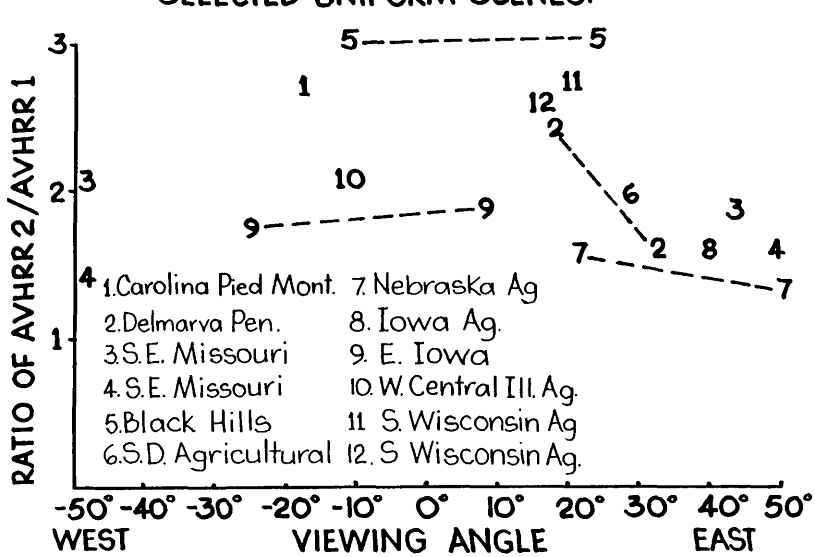


Fig 5. RATIO OF AVHRR (CHANNEL 2/CHANNEL 1) AS A FUNCTION OF VIEWING ANGLE FOR SELECTED UNIFORM SCENES.



An example of atmospheric modelling is shown in Figures 6 and 7. In this (preliminary) analysis, the ground is assumed to have a goniometrically isotropic (Lambertian) reflectance at those wavelengths considered; the reflectance factors are considered to be 0.15 and 0.30. The atmospheric optical depth is taken to be 0.45 in this simulation. The sun-target-sensor geometries considered approximate to those of NOAA-6 and of NOAA-7. This work, based on Dave's models of the atmosphere will be extended to include goniometrically anisotropic ground reflectance. In order to achieve this goal, we will include calibrated ground reflectance models into such simulation studies, so that the fictitious Lambertian assumption will not be made.

CONCLUSION

The approach chosen (the combined modeling and empirical analysis) appears to be the proper one for this problem. While existing models provide an initial estimate of effect of non-Lambertian reflectance and atmosphere, the combining of these into a single comprehensive estimator is a necessary but complex task. The available NOAA AVHRR data appears to be ideal, for providing an initial corrector, for test data for existing models and as a basis from which more comprehensive descriptors can be developed. Software in development that will simplify registration of areas of study viewed and illuminated from a variety of configurations will expedite the follow up to the early work described here.

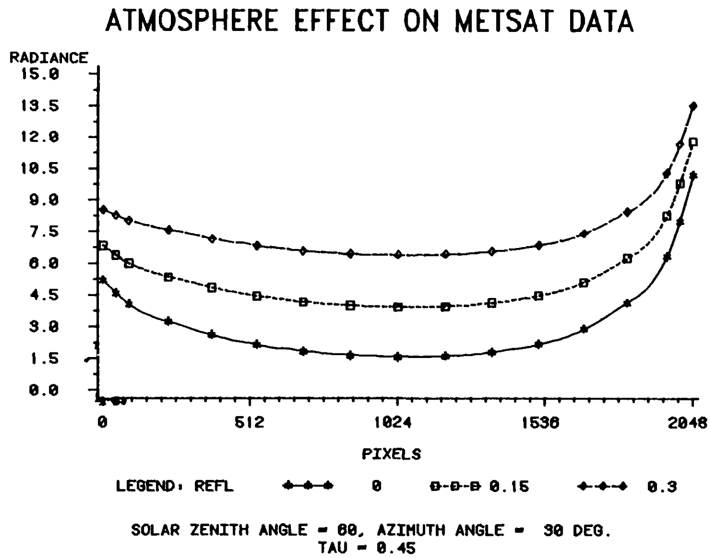


Fig. 6. Atmosphere Effect on Metsat Data (NOAA 6).

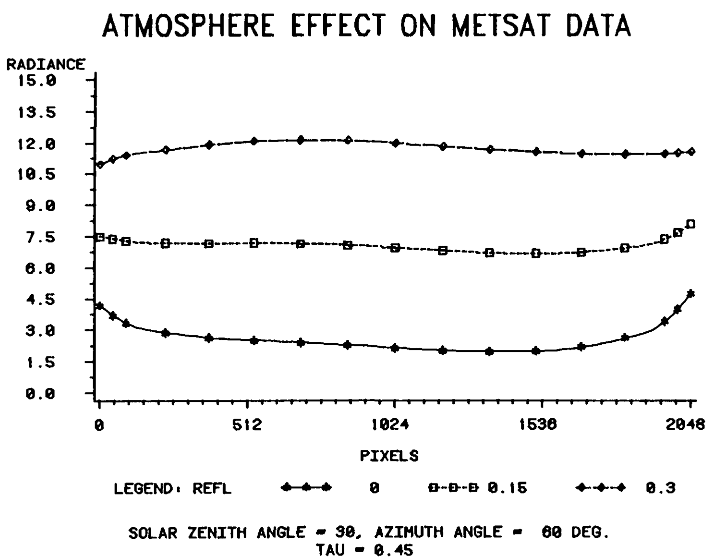


Fig. 7. Atmosphere Effect on Metsat Data (NOAA 7).

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BIVARIATE CONSTRUCTION OF EQUAL-CLASS THEMATIC MAPS

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ABSTRACT

Shaded choropleth maps normally divide their data into discrete classes, rather than symbolizing them as a continuous distribution. In practice, five to ten categories are normally used, rarely more than twenty. Class intervals for data can be established which have equal value ranges, equal numbers of observations, or unequal sizes; the latter variety may be derived by factoring, clustering or statistical grouping procedures. This paper presents a generalization of equal-membership classification, in which class intervals for a mapped variable are fashioned to include equal amounts of a second, related variable. This usually yields unequal ranges for the mapped variable, but the ranges are easier to interpret as they equalize some selected quantity. Maps employing such classifications may give superior insights into the joint distribution of the mapped and classifying variables. Following a discussion of value classification issues, the concept of bivariate classification is introduced and discussed; a procedure to accomplish it is described, and a Fortran implementation of it is given. A series of maps illustrate the results of bivariate classification for a group of related statistics.

1.0 ELEMENTS OF SHADED MAPS

Shaded maps communicate three essential elements of information to map readers, and require map makers to make decisions regarding all three. These elements are:

1. A geographic region, subdivided into zones;
2. Attributes of the zones, grouped into classes;
3. Symbolism shading each class with a certain pattern or color.

Map makers must usually decide upon each of these elements, although in particular cases one or more of the elements may be given. Frequently, element 1 is not a matter of choice, as both the region and its subdivisions are determined by the thematic data which one has and wishes to map.

Computer cartographers usually define their own value classifications and shading for maps they produce. Usually these are specified independently; Once the number of levels is decided, a method of classification is then chosen (which may be automatic or manual) which creates class breaks at certain points along the Z-value range. All zones with values lying between two adjacent breakpoints are thus grouped into the same category, and will be symbolised on the map with the same texture, darkness and color. Symbolism for each class is then defined which may vary its appearance systemmatically according to Z-value, or it may not; although rarely desirable, two levels can be defined to have the same shading, and these levels need not be adjacent ones in the value range. Most map makers will make each level as distinct as possible, and will choose shading patterns with a progression of tones to represent the overall range of Z-values. Occasionally this is accompanied by changes in the design of shading patterns, for instance by using dot patterns to represent lower levels, line patterns for middle levels and crossed line patterns to represent upper levels. Such variations in pattern and texture help readers discriminate among a larger range of classes.

2.0 CLASSIFYING CHOROPLETH MAPS

Despite a rich cartographic literature on the subject, only a small number of value classification techniques are employed in published thematic maps. Most such maps are choropleth (shaded zone) representations, a large portion of which display continuous (as opposed to categorical) thematic data group their observations into a small number of classes, usually with equal value ranges. Few other methods (aside from logarithms, roots and related arithmetic transformations) commonly are employed to communicate thematic regularities of spatial data in shaded maps.

Although many methods have been developed to analytically classify thematic variables, their currency remains limited and largely academic. This is due both to complexity of methodology (such as cluster and principal components analyses), and to the non-intuitive nature of their results, which are too often presented without adequate discussion of the classification procedures employed.

Most statistical classification techniques are designed to maximize value homogeneity of resulting classes. Some methods attempt to do so in the spatial domain, others in the value domain, and some in both. Criteria such as proximity, compactness and contiguity are used to maximize spatial homogeneity, whereas tests such as chi-squared and f-ratio are used to segregate values into classes without regard to their spatial properties.

The main alternative to maximizing intra-class homogeneity is to attempt to maximize the equality of classes. Such techniques are both simple to apply and straightforward to interpret. The two predominant ones are (a) equal value ranges and (b) equal value frequencies. By keeping either the class intervals or the class memberships constant, a map helps its readers interpret spatial patterns because the "importance" of each class is made equal by a simple rule.

There is another form of equal classing, normally employed for dot-distribution mapping, but rarely in choropleth maps. This method strives to equalize the number of objects represented by each symbol, such as the number of people, acres of agricultural land or volume of business transactions. This implies that the data are extensive in nature, rather than intensive -- that is, individual observations must be capable of being summed to a meaningful total. While this excludes many forms of data (e.g., densities, per capita ratios and other intensive measures), in many cases the components of such data (such as population and area) can be used, as will be shown. It is thus conventional cartographic wisdom to use shading to portray intensive quantities, (densities or ratios); when shading intensity varies, it serves as a natural visual analog for such data. For this reason cartographers are critical of maps of extensive quantities in choropleth form; when shading density symbolizes extensive quantities, variations in the area of zones can perceptually bias interpretation.

It is nevertheless possible to portray absolute data on a choropleth map, and do so without areal bias. One way to do this is to use the third dimension, creating a surface. One can make the height of the surface over a zone proportional to either an absolute value or an intensity. The former procedure, however, produces the same problems as does shading absolute values; large zones can visually dominate small ones even if their thematic values are less. However, if the height is made proportional to the areal density of some quantity, such as population, then the volume thus created is proportional to the size of that quantity in that zone. While map readers may not always be able to estimate the relative size of volumes (especially if their shapes change), such a three-dimensional representation is at least honest, in that:

1. Area of zones can be accurately portrayed in the x-y plane;
2. Heights of zones are proportional to densities;
3. Volumes of prisms are therefore meaningful, the integral of density over area.

The result is in one sense a bivariate map as both population size and population density can be read from it.

Not every cartographer has access to software for plotting 3-d prism maps, and such maps are difficult to construct manually. Furthermore, clients still tend to prefer 2-d choropleth maps over 3-d ones, especially in application areas such as social science and marketing. It would thus be convenient and practical to offer their advantages in two dimensions (as conventional shaded maps), which the procedure described below can begin to accomplish.

3.0 WHAT ARE EQUAL CLASSES?

An equal-interval classification is normally regarded as one in which the range of data values (or some standardized range, such as zero to one hundred percent) is partitioned into exactly equal parts. One assigns shading to such a set of intervals, as one would apply hypsometric tints to a contour map. Once the number of classes and the overall data range are selected, the sizes and limits of all intervals are completely specified. Consequently, the particular distribution of data values (aside from their lower and upper limits) has no effect on the results. This is why equal-interval classes are usually a poor choice when mapping skewed value sets, such as population densities.

When very non-uniform statistics are mapped into equal intervals, one or two classes (often the lower ones) may contain the bulk of the observations, and thus not communicate their variation. Likewise, some classes (usually in the middle range) may end up devoid of observations, reducing the information content still further. The greater the number of classes and the fewer the number of zones to be symbolized, the more likely this is to occur.

Figure 1 is a shaded map of U.S. state population densities, classified into 5 equal-sized intervals, each spanning a range of 200 persons per square mile. Due to the non-uniformity of this value distribution, fully 38 states, or 78 percent, fall into the lowest class. The resulting map is a caricature of the data, with little graphic utility. The main order of business for such a map is to communicate the spatial distribution of population. Toward this end, it might be useful to modify class intervals to reflect the properties of that distribution. That is, why not equalize the contents of classes rather than their extents? To do this, we can reclassify densities in any of three fairly obvious ways, grouping them into classes which contain:

1. Equal numbers of observations,
2. Equal areas, or
3. Equal populations.

The first option should be familiar to thematic cartographers, being the so-called "quantile" method of classification, more generally known as Histogram Equalization. In maps where unit areas are constant, such as images or other gridded data, this procedure is tantamount to the following one, equal-area classification, yielding the same results. For choropleth maps of most real geographies, however, they are not the same, and thus option 1 is a special case of option 2. The results of a quantile classing of the data mapped in figure 1 is the map shown as figure 2. Here each class contains about 10 states, identifying those states ranked in the bottom fifth of population density, second fifth, etc. Note that the classes are of variable extent, but that in terms of membership they are equal.

3.1 Equal-area Classification

To standardize the areas occupied by each class in the general case, a second set of values -- the area of each zone -- must be available and incorporated into the classification process. This turns the procedure from a univariate to a bivariate one, a subroutine for accomplishing which is listed in Appendix I. To equalize class area, this processor reads in data records containing both population density and area for each zone in a region, sorts the records by increasing population density and simultaneously computes total land area. This total is divided by the number of classes to be portrayed, yielding its average, the area which each class should ideally cover. Then, proceeding up the sorted list of densities, zone area is accumulated until this average size has been achieved; the value of population density given for this observation then defines the upper limit of the first class. Repeating this procedure until the highest density is reached computes a set of class breaks which partition the data into classes of roughly equal area. These breaks are then used to classify and map population densities. The more observations which exist, the more accurate this process can be. With the U.S. states, especially if Alaska is included, equal-area classing can be somewhat imprecise, the amount of error depending on what quantity is being mapped. Figure 3 presents a map of densities classed to have equal area. This, rather than figure 2, approximates a Histogram Equalization for the data, given that land area varies from state to state.

3.2 Equal-population Classification

Approximate as it may be, this simple procedure for deriving equal-area classes is remarkably general; one soon realizes that attributes other than area can be equalized just as easily, and this leads to consideration of option 3, equal-population classification. Specifically, each class can be fashioned to include an equal number of people, simply by substituting population counts for land area when classifying population densities. The results of this substitution are displayed as figure 4. Each of the five classes in that map contain forty to fifty million persons, specifying the range of densities at which respective fifths of the U.S. population live, at the state level.

3.3 Equal-income Classification

If thematic classes can be fashioned to standardize the number of people which each contains, clearly they can likewise be computed to partition any extensive (countable) quantity of interest. To demonstrate that the technique of class equalization is independent of the data it manipulates, consider the map displayed in figure 5. In this map, population densities are again aggregated into 5 levels, but classified so that each one contains equal amounts of disposable personal income. Although population densities and income may be empirically correlated, these two statistics measure different phenomena and have no common factors. Yet, one expects that urban regions will generate income more rapidly than rural ones, even if the specific causalities are not understood. Figure 5 is an attempt to spatially simplify this relationship. The constriction of top-level symbolism in it indicates a concentration of wealth in the most dense states.

4.0 FURTHER EXPLORATIONS

The final three maps, figures 6, 7 and 8 further illustrate bivariate classification, changing the thematic variable to income per capita by state for the U.S. in 1979. While population densities have a highly skewed, almost lognormal distribution, per capita incomes are nearly normally distributed, slightly skewed to the left, as the histograms show in the last 3 maps. Consequently, an equal-interval classification is much more appropriate for this data; figure 6 shows the result of this, in which each of six classes covers a span of 1000 dollars per capita. While far more informative than figure 1, figure 6 still obscures a certain amount of data. As the U.S. is predominantly a middle-class nation, important distinctions may be blurred in the middle income ranges by using equal-interval classes.

Classifying these data to equalize population-per-class (figure 7) yields a different pattern of symbolism. This map might be considered to be "more representative" of the distribution of income levels, as the population represented by each class is now nearly equal, being about 33 million people. The fact that the largest number of states is found in the bottom class indicates that there is probably a positive correlation between income levels and population size, if not population density. (This insight may help one to re-interpret figure 5, in which population density is grouped into classes with equal aggregate income.) Notice also that figure 7 seems to draw firmer distinctions than figure 6; for instance, Colorado and Nebraska both occupy class 3 in the equal-interval map, but in the equal-population map Nebraska has gravitated down to level 2 and Colorodo has risen to level 4, as level 3 now has a much smaller value range. The author leaves the reader with the exercise of comparing figure 8 to figures 7 and 6. Examine the differences in class breaks; what generalizations can be made about an equal-income classification of per capita income in comparing it with the equal-interval and equal-population maps?

5.0 CONCLUDING COMMENTS

Communicating the patterns in which living communities group themselves is thematic cartography's essential challenge and its special competence. Maps which display single variables may be easier to interpret than bivariate ones, but can never really express the richness of relationships which characterize living systems. Although all maps are simplifications of reality, the use of a second variable in classifying a coverage can deliberately add information without greatly burdening the map reader, if carefully employed. It would certainly be easy to abuse bivariate classification, by attempting to associate completely unrelated variables. It is equally tempting and easy to compute spurious correlations between variables with statistical analysis packages. As in all data processing, Garbage In, Garbage Out. One may nevertheless have special and valid reasons for looking at associations among variables which other analysts may not regard as having any important relationship; one person's data can be another person's trivia. In any case, the burden of proof should be on the mapmaking analyst, who must provide a framework within which bivariate (or any) maps may be interpreted. The framework may be a theoretical model, hypotheses concerning interesting empirical regularities, or it may simply be a set of maps and measures designed to describe certain spatially distributed thematic variables. At the very least, viewing thematic maps classified in several different ways can inform one of more nuances of spatial structure than any single map can communicate.

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The literature of thematic cartography in general and classification techniques in particular is quite extensive. No specific references have been cited in this paper, however, due to the exploratory nature and apparent novelty of the material presented. While the technique for bivariate classification it presents is not complicated, and may even be regarded as fairly obvious once explained, the author has never encountered it in print. This is somewhat surprising, and may constitute an admission of ignorance; if any reader is aware of similar work, reported in the literature or unpublished, the author would welcome learning of it.

APPENDIX I

FORTRAN Procedure for Computing Bivariate Classifications

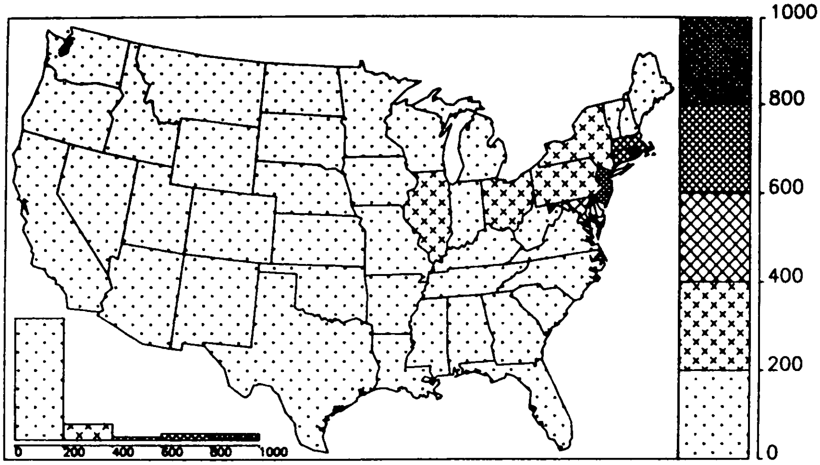
```
      SUBROUTINE CLASSY (V1,V2,NVAL,BREAKS,BINS,NCLASS,V2SUM,BAD)
C
C   DOES CLASSIFICATION OF VALUE LIST ACCORDING TO EQUAL AMOUNTS
C   OF A SECOND QUANTITY, RETURNING CLASS BREAKS.  IT IS ASSUMED
C   THAT BOTH VARIABLES ARE REAL, RATIO QUANTITIES.
C
C     GEOFFREY DUTTON, HARVARD LABORATORY FOR COMPUTER GRAPHICS
C     AND SPATIAL ANALYSIS;  AUGUST 1982.
C
C     V1     - VARIABLE LIST TO CLASSIFY
C     V2     - CLASSIFYING VARIABLE LIST
C     NVAL   - NUMBER OF OBSERVATIONS (FOR V1 AND V2)
C     BREAKS - VECTOR OF CLASS BREAKS
C     BINS   - HISTOGRAM OF CLASSIFIER
C     NCLASS - NUMBER OF CLASS LEVELS
C     V2SUM  - SUM OF CLASSIFYING VARIABLE
C     BAD    - INVALID DATA FLAG
C
      DIMENSION BINS(NCLASS)
      DIMENSION V1(NVAL), V2(NVAL), BREAKS(NCLASS)
      DIMENSION INDEX(5000), V1SORT(5000)
C
C             FIRST CREATE INDEX POINTERS
C             AND SUM WEIGHTING VARIABLE
C
      V2SUM = 0.0
      DO 10 I = 1,NVAL
        INDEX(I) = I
        VAL = V2(I)
        IF (VAL .NE. BAD) V2SUM = V2SUM+VAL
        V1SORT(I) = V1(I)
   10 CONTINUE
C
C             ZERO OUT THE BINS ARRAY
C
      DO 15 I = 1,NCLASS
        BINS(I) = 0.0
   15 CONTINUE
```

```
C
C              SORT THE PRIMARY VARIABLE AND AN INDEX TO IT
C
      CALL SORT (V1SORT,INDEX,NVAL)
C
C              V2BAR IS HOW MUCH OF V2 EACH CLASS SHOULD GET
C
      V2BAR = V2SUM/FLOAT(NCLASS)
C
C              NOW ASSIGN VALUES TO CLASSES, VERY SIMPLY
C
      KLASS = 0
      VSUM2 = 0.0
C
      DO 20 I = 1,NVAL
        J = INDEX(I)
        VAL = V2(J)
        IF (VAL .NE. BAD) VSUM2 = VSUM2+VAL
        LEVEL = VSUM2/V2BAR
        IF (VAL .NE. BAD) BINS(LEVEL+1) = BINS(LEVEL+1)+VAL
        IF (LEVEL .LE. KLASS) GOTO 20
C
C              NEW LEVEL REACHED; SOME OF V2 SPILLS INTO NEXT ONE
C
        J0 = INDEX(I-1)
        BREAKS(LEVEL) = (V1(J)+V1(J0))/2.
        KLASS = LEVEL
   20 CONTINUE
C
      RETURN
      END
```

FIGURES

The following maps of the U.S.A. by state demonstrate the use of bivariate classification. These illustrations were produced by the POLYPS program, the 2-d choropleth mapping module of the Laboratory's ODYSSEY Geographic Information System. POLYPS was written by Scott Morehouse.

STATE POPULATION DENSITIES, 1975

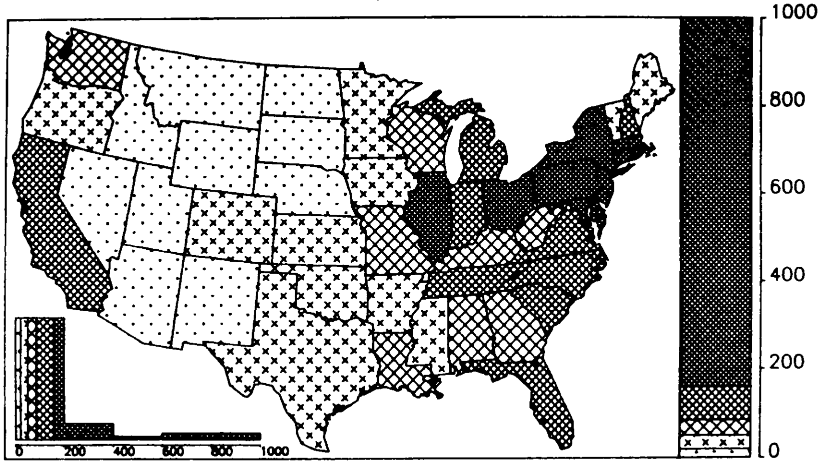


AN EQUAL-INTERVAL CLASSIFICATION

Class contents are: 200, 200, 200, 200, 200 persons/sq. mile
Class breaks are: 200, 400, 600, 800 persons/sq. mile
Class Memberships are: 38, 5, 1, 2, 2 states.

Figure 1

POPULATION DENSITIES, 1975

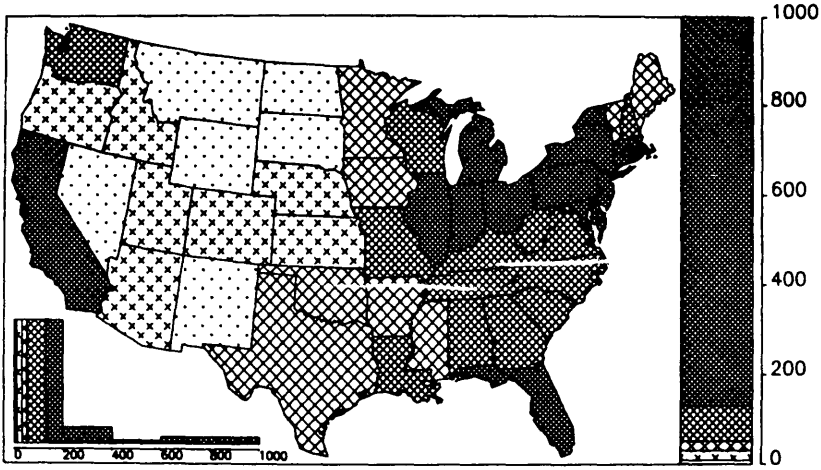


EQUAL-MEMBERSHIP (QUANTILE) CLASSIFICATION

Class contents are: 10, 11, 8, 9, 10 states
Class Breaks are: 20, 51, 85, 160 persons/sq. mile;
Class Memberships are: 10, 11, 8, 9, 10 states;

Figure 2

POPULATION DENSITIES, 1975

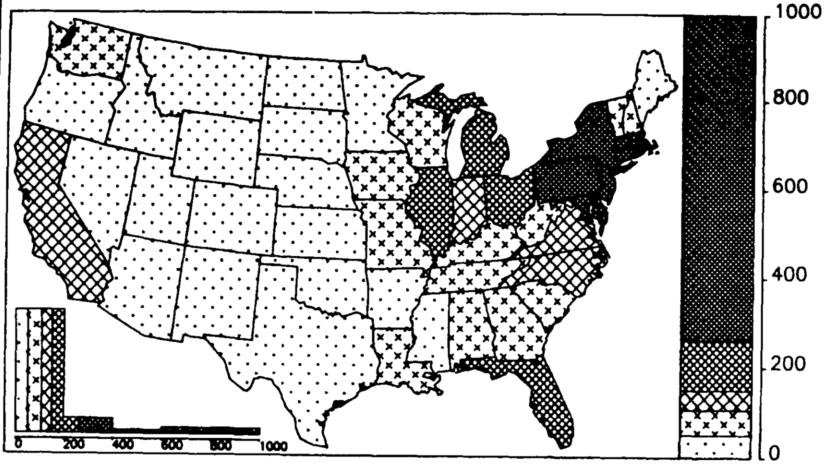


EQUAL-AREA CLASSIFICATION:

Class contents are: 522, 636, 606, 577, 526 square miles;
Class Breaks are: 9.5, 31, 52, 130.5 persons/sq. mile;
Class Memberships are: 6, 7, 8, 13, 14 states

Figure 3

POPULATION DENSITIES, 1975

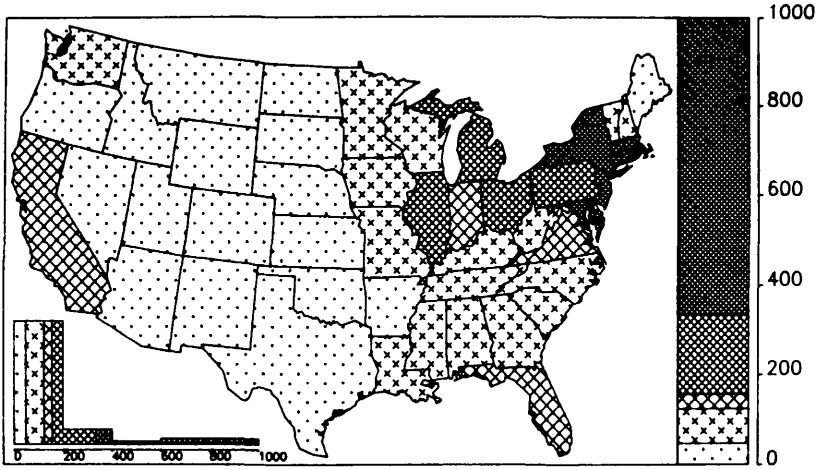


AN EQUAL-POPULATION CLASSIFICATION:

Class contents are: 38.7, 39.4, 34.8, 43.5, 39.4 million persons;
Class Breaks are: 50.5, 106.5, 150, 263 persons/sq. mile;
Class Memberships are: 22, 13, 4, 4, 8 STATES;

Figure 4

POPULATION DENSITIES, 1975

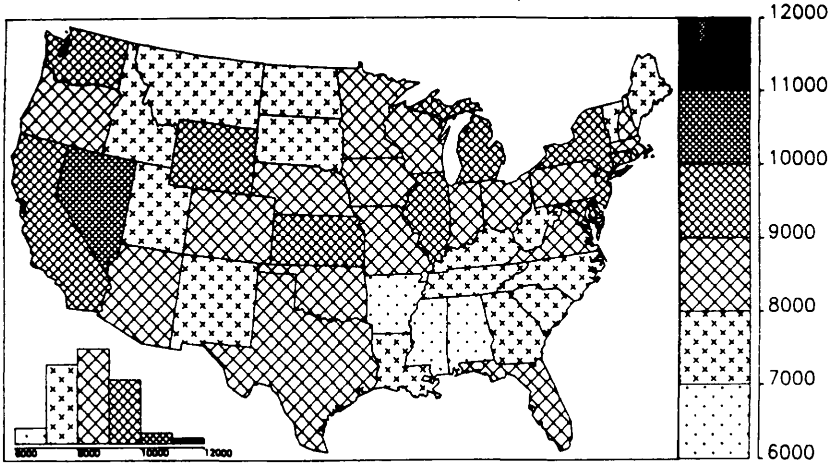


AN EQUAL-INCOME CLASSIFICATION

Class contents are: 333, 341, 348, 395, 359 billion dollars;
Class breaks are: 48, 124, 156.5, 335 persons/sq. mile;
Class Memberships are: 20, 16, 4, 5, 6 states.

Figure 5

DISPOSABLE INCOME PER CAPITA, 1979

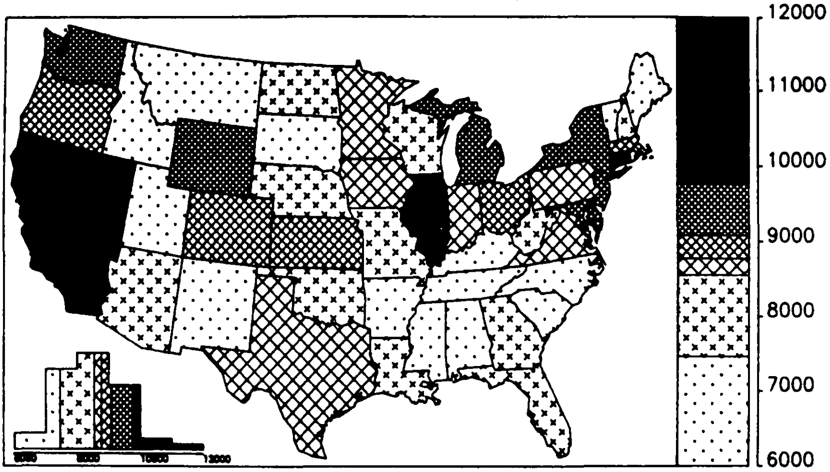


EQUAL-INTERVAL CLASSIFICATION

Class contents are: 1000, 1000, 1000, 1000, 1000, 1000 $/person
Class breaks are: 7000, 8000, 9000, 10000, 11000 $/person;
Class memberships are: 3, 15, 18, 12, 2, 1 states;

Figure 6

DISPOSABLE INCOME PER CAPITA, 1979

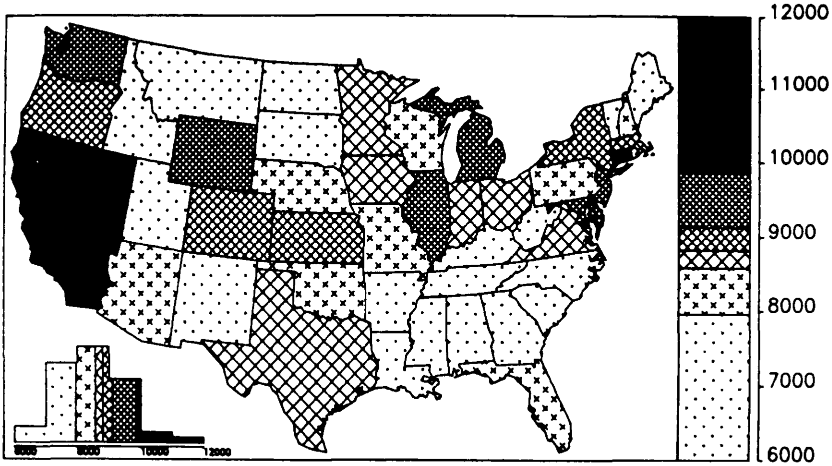


EQUAL-POPULATION CLASSIFICATION:

Class contents are: 30, 30.7, 36.2, 23.6, 39.2, 36.1 million people
Class breaks are: 7462, 8546, 8768, 9077, 9762 $/capita;
Class memberships are: 14, 12, 6, 5, 8, 6 states

Figure 7

DISPOSABLE INCOME PER CAPITA, 1979



EQUAL-INCOME CLASSIFICATION

Class contents are: 297, 288, 317, 280, 319, 275 billion $
Class Breaks are: 7953, 8574, 8808, 9124 9868$/PERSON;
Class memberships are: 14, 12, 6, 5, 8, 6 states.

Figure 8

MODULARIZATION OF DIGITAL CARTOGRAPHIC DATA CAPTURE

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ABSTRACT

The capture of digital cartographic data, including digitizing, is currently one of the most expensive and labor intensive operations in the field of automated cartography. As a step toward reducing these data capture costs, structured analysis techniques are applied. Map features may be typed by dimensional extent: points, lines, areas, and volumes. Digital cartographic data describing these features may consist of three distinct subsets of data: (1) locational or image; (2) non-locational or attribute; and (3) topological (neighborhood or adjacency). Methods of isolating the capture of each of these data subsets into discrete functional modules and sub-modules are explored. As newer methods of performing these separate functions are developed, they may be "plugged in" as modules without developing new data capture systems.

INTRODUCTION

In recent years we have seen many advancements in the use of digital computers for handling cartographic data. Better ways are being developed for representing, storing, retrieving, manipulating, analyzing, and displaying cartographic data. With the increasing performance and decreasing costs of computing hardware, the dream of using these machines to better help us understand and manage our land and its resources is becoming a reality.

But the initial data capture step remains the primary limitation to the production and use of digital cartographic data. The costs of transferring data on existing graphic maps into machine-readable, and machine-useable (readable is not necessarily useable) forms continues to be high. This is especially true when they are compared to the much lower costs, relatively, of almost all other phases of automated cartography and spatial data handling. Even such complex tasks as polygon overlay, areal generalization, and map compilation (including automated name placement) are, or soon will be, realistically cost-effective processes for large-scale and small-scale endeavors (such as those engaged in planning, marketing, spatial process modeling, or mapmaking). Now, with the exception of simple, low-volume data, this is not the case for digital cartographic data capture.

As with most data input procedures, the high cost of capturing digital cartographic data is related to the level of manual labor required. Manual operations involve preparing source materials for digitizing, coding, verifying, validating, and editing, as well as actually digitizing. The amount of labor required is usually related to the quantity and types of data, both input and output, to be processed. But other labor costs are also incurred as "overhead" of the particular system and set of procedures used in the data capturing process. Some overhead costs are, of course, unavoidable. Poor system design, however, or the inappropriate usage of equipment, systems, and(or) procedures (which may be cost effective for one level or type of data but not for another) also increase costs. If systems could be tailored to the differing requirements of various data levels and types, progress could be made toward reducing data capture costs.

STRUCTURED ANALYSIS METHODOLOGY

The techniques of structured analysis may afford a means of specifying systems for capturing digital cartographic data. These techniques concentrate on the modularization (partitioning) of a system based upon the flow of data, definition of data components, and minimization of interfaces among data transformation processes (DeMarco, 1979). An activity to be modeled consists of two types of entities: data and processes. Data may be considered as the passive entities (or objects) of an activity. Processes are the active entities (or verbs) of an activity and are defined initially by their data inputs and outputs. An activity is ultimately modeled by the diagramming of data flows which ties all data and processes into one coherent systematic description.

Structured analysis further facilitates modularization by the top-down hierarchical approach to the definition of processes and data. An entire activity may be considered as one process with data inputs and outputs. It is then further partitioned into sub-processes, each with its own data inputs and outputs, until the lowest level of functional modules have been defined. The method of partitioning is not from a functional (or internal process) viewpoint, however, but from the view of the data. An analysis follows the data through an operation, concentrating on distinctions among data inputs and outputs. Functional modules are the result of the methodology, but data and data flows are its driving force.

One principal feature of system designs based upon this methodology is a high degree of module independence. The less the internal implementation of one module (how its function is performed) depends upon another module, the more independence is achieved. This greatly facilitates maintenance and adaptation of a system to changing requirements and improved techniques.

DIGITAL CARTOGRAPHIC DATA COMPONENTS--PART I

The first step in modeling the data capture process is to define its data inputs and outputs. This also presents the opportunity to outline the context and scope of the present definition of the data capture process. The input to the data capture process is defined here as a cartographic representation (i.e. a graphic map) of phenomena on some portion of the Earth's surface (or any portion of space), possibly including non-cartographic data which describe the same phenomena. The output is a digital representation of the same data about those phenomena or some subset of that data. Since the data input to and output from the data capture process may be considered the same, only in different forms, cartographic data may be discussed in the abstract, regardless of form.

The real component of a cartographic data set is called a "feature." A feature, to review this basic cartographic term, is some object or cohesive phenomenon on or near the Earth's surface which may have some significance. Examples of features include a building, road, stream, woodland area, spot elevation, town, county boundary, etc. All other components described below are actually characteristics of either individual features, or of a collection of features most term a "map" or an "overlay."

Feature Types Based Upon Dimensional Extent

One method of partitioning cartographic data is by dimensional extent. Feature dimensional extent may be of one of the four dimensions: zero for point features, one for linear features, two for areal features, and three for volumetric features or surfaces. Actual features may contain entities of more than one dimensional extent, but for now assume features are entities of a single dimensional extent type. Hereafter, when reference is made to a feature type, it is based solely upon its dimensional extent.

Dimensional extent may refer to both real world and digital representations. It should be noted that many real world volumetric and areal features will have digital representations as points or lines, depending upon the spatial resolution of the digital representation. Most often rivers and transportation routes will be represented as linear features even though they occupy areas on the Earth's surface. When this is taken into consideration, it can be seen that there may actually be four feature types in the real world, but theoretically up to ten types when coupled with their possible digital representations (see table 1).

	Digital Representation			
Real World Extent	point	line	area	volume
point	0-0			
line	1-0	1-1		
area	2-0	2-1	2-2	
volume	3-0	3-1	3-2	3-3

Table 1. Digital cartographic feature types

DIGITAL CARTOGRAPHIC DATA COMPONENTS--PART II

The next partitioning of digital cartographic data is based upon the logical types of data which may be used to describe either a given feature or collection of features. These components are classified under three broad categories of descriptive data types: (1) locational data, (2) attribute data, and (3) topological data.

Locational Data

Locational data fix a feature or set of features in space, usually using some reference system relative to known locations upon the Earth's surface. Spatial extent, geographical extent, and absolute position are all terms synonymous with location. Space, of course, is three-dimensional so the normal means of specifying a location in space is with the use of X, Y, and Z coordinates relative to three mutually perpendicular axes. For most cartographic data, however, the third or Z coordinate is unexpressed (or suppressed). The data are assumed to exist upon the Earth's surface which is in turn assumed to be a plane or a spheroid.

Note that the logical form of the locational data required to fix a given feature type in space is usually a direct function of the feature type. Within a given cartographic data set, the locational data of all features of one type (e.g. areas) are usually defined in the same logical manner. Conversely, the logical forms of the locational data of different feature types are usually different.

Sub-components of cartographic locational data include resolution, coordinate system specifications, and positional accuracy. Geometric (measurement) data may be derived from locational data.

Attribute Data

Attributes are the non-locational and non-topological data attached to a feature, to a collection of features, or to an entire data set. These data may consist of textual descriptors, discrete feature codes, continuous "Z" values, and(or) some unique label identifier. Ideally, this component should not contain data derived from or indicative of any other feature component (location or topology). Important sub-components of attribute data include theme and category/feature classification system.

Theme concerns the overall classification of the content of a cartographic data set. Ideally, a given data set would consist of only one theme which should constitute a coherent description. Such descriptions of the Earth's surface fall into three broad categories:

- o Artificial subdivisions and features such as administrative, political, census, and ownership boundaries as well as reference systems such as public land surveys;
- o Physical phenomena on (or near) the surface. For example, the overall theme of land use and land cover includes all relatively static (stable) physical phenomena on the Earth's surface; and
- o Surface definition such as hypsography.

A _classification scheme_ (category/feature codes) should be a comprehensive and systematic method of coding all the features of a data set in the context of theme. Note that the classification/feature coding scheme should be structured as much as possible on the basis of the real-world features themselves, rather than their cartographic or digital representations.

Topological Data

Topology refers to essentially nonmetric spatial relationships among the various features on a surface. Topological relationships are not changed by geometric distortions or transformations of the surface as long as the surface is not disrupted. The definitions of the terms "neighborhood function" (Peucker and Chrisman, 1975) and "adjacency" are derived from topological relationships. They reflect an overriding need in the analytical use of cartographic data to know the position of a feature, not only in absolute space, but also with respect to its neighboring features.

The discussion of topological data has been restricted to cartographic data describing features on a continuous surface (e.g. a portion of the Earth's surface), excluding the definition of the surface itself. Feature types are then restricted to three digital representations: points, lines, and areas. To be able to derive the full benefit of topological data, however, it is necessary to further define the entities which may exist within the data set.

All linear features of the data are defined as a set of one or more arcs. An _arc_ is a one dimensional entity whose location may be defined by an ordered series of two or more points, beginning at a node and ending at a node, but not passing through a node. A _node_ is a zero dimensional entity defined as the beginning or ending point of an arc. The only points on the surface shared by any two arcs are nodes (two adjoining arcs share a node). Areal features are defined as a set of one or more polygons. A _polygon_ is a continuous two dimensional entity bounded by one or more sets of adjoining arcs. Each arc set begins and ends at the same node. If more than one set is required to define the polygon, one of the sets is the "outside" boundary of the polygon and the others are separate "islands" within the outside boundary. The cartographic surface consists of polygons which are mutually exclusive and which completely exhaust the surface. Arcs must either define a boundary or portion of a boundary between two and only two polygons (adjacent polygons share an arc), or be totally contained within one polygon. In this set of definitions, point features may be represented as "degenerate" arcs (with only one point unconnected to any other arc), or as true node points shared with one or more arcs.

For data defined in this arc-node-polygon structure, the following topological relationships exist (see table 2): (1) for each arc, (a) arc(s) adjoining, (b) start-node and end-node, and (c) polygon-right and polygon-left; (2) for nodes, (a) arc(s) terminal, (b) nodes sharing arcs, and (c) polygon(s) adjacent; and (3) for polygons, (a) bounding arc(s), (b) bounding node(s), and (c) polygons adjacent. Other relationships may be derived from these (e.g. second and third order neighborhood functions), but these relationships may be considered the primary ones.

		Arcs	Nodes	Polygons
(1)	Arcs	(a)	(b)	(c)
(2)	Nodes	(a)	(b)	(c)
(3)	Polygons	(a)	(b)	(c)

Table 2. Arc-node-polygon topological relationships

Note that there are several redundancies in these relationships. All relationships may be derived from just the start-node and end-node and polygon-left and polygon-right of arcs, and even these relationships are symmetrical (Corbett, 1975). To reverse the order of the points of an arc is to reverse both the start-node and end-node, and the polygon-left and polygon-right relationships.

A PROPOSED CARTOGRAPHIC DATA CAPTURE MODEL

Once a cartographic data set has been broken down into components, a simple model of the data capture process can be built. The model must, of course, include inputs as well as outputs. It is assumed, however, that the inputs and outputs of the data capture process may be considered, with some exceptions, to be logically the same, only in different forms. We begin with points, lines, and areas displayed on a graphic map and we end with points, lines, and areas in digital form.

The model cartographic data set has been partitioned by both feature type and by descriptive data type. The matrix of these two methods yields a framework by which the data capture process may be modularized (see table 3).

	Descriptive Data Type		
Feature Type	Location	Attributes	Topology
Point (0)	0a	0b	0c
Line (1)	1a	1b	1c
Area (2)	2a	2b	2c
Volume (3)	3a	3b	3c

Table 3. Feature type by descriptive data type components

In the ideal digital cartographic data capture model, each of the 12 components in table 3 would have one or more separate data capture process modules. The inner workings of each of the modules would be independent of the internals of other modules. Simply stated, the collection of location, attribute, and toplogical data should be separate operations; and capture of point, line, area, and surface data should likewise involve separate procedures.

Other methods of partitioning the cartographic data set, particularly those more oriented to the input data, will provide definitions of further data capture modules. The consideration of real-world dimensional extent versus digital representation (see table 1) might dictate distinct submodules for a given feature type. In addition, subpartitioning of attribute data, especially by overall theme (i.e. category), will generate other data capture submodules.

Standardizing Data Input

In order to develop a pratical data flow diagram of the data capture process, attention must now be directed to the input side. If input consists of two dimensional objects--graphic maps or images (aerial photographs or other remotely sensed images), an initial distinction can be made between (1) volumetric or surface definition data and (2) planimetric data of point, line, and areal features.

Volumetric/surface data require either (a) a pair of input two dimensional images, or (b) a reduction to one two-dimensional object (e.g. contour lines) plus associated "Z" values which may be considered attribute data. The second case may be considered, for data capture purposes, a type of planimetric data. The first case, however, requires a separate data capture process. The first case will not be considered further here, except to say that some process may be defined which results in the second case.

The first step in the data capture process, therefore, is the standardization of the input data to point, line, and areal features on a two-dimensional graphic map. This is often a generalization step which, in most cases, is part of the normal (i.e. manual) map compilation process. The output from this step consists of two parts: (1) a line graph, the graphic representation of points, lines, and areas, and (2) attribute (including "Z" values) data associated with either collections of features or individual features. These attribute data may or may not be physically part of the graphic map and may be textual and(or) graphically symbolized.

A Proposed Data Capture Flow

The digital components of the matrix in table 3 (minus the volumetric feature type) may now be related to the "analog" input data by diagramming the processes and data flows between them (see figure 1).

Attribute Encoding. The collection of non-graphic attribute data has been covered elsewhere (e.g. Wooldridge, 1974). The present discussion of non-graphic data capture will be limited to the processes by which the non-graphic attributes are related to locational and(or) topological data. Some attribute data, however, may exist in graphic form (e.g. symbolized transportation routes and color-coded areas), and may involve quite different encoding processes. But from the viewpoint of the flow of data (inputs and outputs), all attribute encoding processes are fundamentally similar and, more importantly, logically separate in concept from the capture of location and topological data.

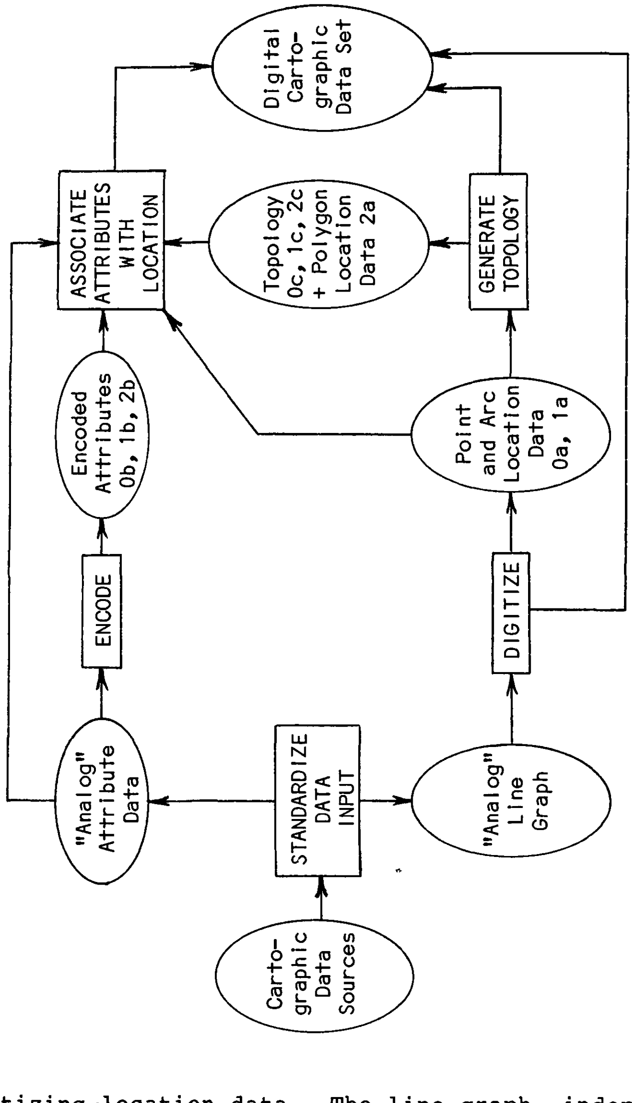

Figure 1. Digital cartographic data capture flow diagram

<u>Digitizing location data</u>. The line graph, independent of attributes, may be seen to consist of the entities (arcs, nodes, and polygons) outlined under the discussion of topological data above. Since polygons may be defined by their sets of arcs, and nodes are defined as end-points of arcs, the capture of all locational data can be considered as the digitizing of arcs. Point features are special cases (either nodes or one-point arcs) and may be handled differently. Digitizing the line graph therefore consists of two processes, each yielding a set of location data--one for point data and one for arc data.

<u>Generating topology</u>. Once the point and arc locational data have been digitized in a logically correct form (different methods of performing these processes may require

various editing and clean-up sub-processes), all first-order (primary arc-node-polygon relationships) topological data may be derived automatically. This is possible because of the initial standardization of the graphic input map into line graph form. The topological relationships among the entities of the graph, although independent of _absolute_ fixed location, are inherent in the _relative_ positions of the entities. Location, therefore, dictates topology. Also, the locational data of polygons (defined by the arcs which bound them) are inherent in the topological data.

Associating attribute data. At this point, all that remains necessary to complete the descriptions of the individual features are the processes which tie the attribute data to the locational and topological data. These processes have traditionally been part of the initial digitizing or encoding processes. As the position of a given feature is digitized, attribute data are encoded at the same time. It is proposed here to isolate, as much as possible, the collection of all three descriptive data types. This does not mean that the association of attribute data with locational data should not be allowed at initial digitization. Although separate processes are recommended, the association process should be possible at any time, for any features.

Note that in figure 1 a number of separate processes have been combined for the sake of simplicity. The association of attribute data with the locational and topological data might involve separate processes for each feature type. The digitizing of point and line data might also involve separate processes, with the understanding that some editing and verification procedures would follow the initial digitization. The generation of all topological data, however, is seen as one basic process with possible point and line subprocesses.

All processes diagrammed at the level shown in figure 1 can be broken down into sub-processes and further. This is a first attempt at an overall first-level partitioning of the data capture process. Before any practical design can be based upon the diagram, much more work must be done.

IMPLEMENTATION CONSIDERATIONS

The actual manner in which the various data capture subprocesses are implemented, as has been noted, should be a function of the characteristics of the specific cartographic data to be captured. Most characteristics having impact upon the data capture process have been categorized and generalized above by feature type and descriptive data type.

Data Volumes. One important data characteristic not covered above, and which does have impact upon the data capture process, is the volume of data. The manner in which data are most efficiently collected from a graphic map with a few sparse features (e.g. a county map of Delaware) might be quite different from the best methods to collect densely populated, high-volume data (e.g. a 20,000 polygon land use map of Connecticut).

Data Structures: An additional consideration which may seem to be important is the logical data structure into which the captured data will be placed. The entire discussion so far could be construed to relate only to the arc-node-polygon topological data structure. There are other structures used to handle cartographic data--"pure images," raster data, grid cells, "pure polygon," and "spaghetti" (Chrisman, 1974). It is proposed here that for point, line, and areal features, all cartographic data structures in use today may be derived automatically and efficiently from the arc-node-polygon structure. Furthermore, the logical view of the input graphic map as an arc-node-polygon line graph does not necessarily mean that the generation of the topological data is mandated, or even that a vector (as opposed to raster) organization is required. The logical components of a digital cartographic data set, regardless of structure, are outlined in table 3. The differences among structures relate to the internal organization of these components, and to the absence or presence of certain components.

CONCLUSION

An initial attempt has been made to apply structured analysis techniques to the definition of the digital cartographic data capture process. These techniques partition a process into functional modules by defining data inputs, outputs, and flows. The resulting discrete data capture modules, defined from the viewpoint of the data, should exhibit a high degree of modular independence. The inner workings of one module should be isolated as much as possible from those of other modules. Such isolation will allow the most flexible use of different methods of capturing the different cartographic data components. The specific methods used may be tailored to the characteristics of a given cartographic data set. Also, as newer and more efficient methods are developed to perform the various data capture sub-processes, they may be "plugged in" without developing entire new systems.

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DIRECT DIGITAL MAPPING

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The Good, Bad, and Ugly of Direct Digital Mapping

This paper will address the good, the bad, and the ugly of direct digital mapping. Throughout this paper, the term "good" will refer to the benefits of direct digital mapping. The term "bad" will focus on the day-to-day problems of direct digital mapping. The term "ugly" will focus on dealing with the proposed client of direct digital mapping.

Direct digital mapping is the gathering, converting, and storing of x and y or x, y, and z geographic coordinates from existing maps, plans, or aerial photographs into a machine-readable format. There are many ways of going about capturing geographic coordinates.

- Directly from aerial photography or photo enlargements using a digitizing table.
- Directly from the aerial photographs using a stereo plotter or analytical plotter.
- Using a digitizing table and digitizing pencil manuscripts or the finished drafted topographic/ planimetric maps.
- Using a digitizer and digitizing ortho photo maps.
- Automatically scanning the final drafted map or pencil manuscript using automated scanning equipment.

There are many and varied reasons as to why one needs or thinks one needs direct digital mapping. These reasons tend to be the good of direct digital mapping.

One of the main reasons for implementing direct digital mapping is to create a common base of x and y geographic coordinates to produce and use as an integrated collection of spatially related information. In most large organizations, each department has its own set of special purpose maps at various scales and various degrees of currency. All of these maps have a common trait which is "geographic location." These geographic locations are the location of rights-of-way and/or roads, drainage, railroads, and street names. Typical overlays to these maps are parcels, waterlines, electrical lines, wastewater lines, telephone lines, planimetric detail, structures, sidewalks, etc.

The City of Houston, Texas, for example, has over 60 different series of maps at various scales. There has been a constant struggle to keep the different series of maps current. One new subdivision created within the City needs to be added to 60 different sets of maps. With direct digital mapping, new subdivisions could be added once and then each department user would only need to add his particular utility, parcel, or other information.

Direct digital mapping makes it possible to produce different scale maps of selected common data of the same geographic area. A 1:500 map may contain street structures, light poles, street names, item names such as parking, fire hydrants, school names, rights-ofway, parcels, parcel dimensions, etc. A 1:5,000 map may contain only the streets, structures, and street names, and a 1:50,000 map may contain only the streets.

Direct digital mapping is cost effective to an organization--whether it is used internally by a mapping company to lower its production and labor cost or for a user who finds direct digital mapping and its uses cost effective. For either the private company or government entity, the economics of direct digital mapping are elementary. The investment must be recovered by reducing production and/or labor costs and therefore increasing production of new and more useful maps at a lower cost.

When examining map production, the labor cost of the photogrammetric stereo compilation, and cartographic drafting has a 40 to 60 percent ratio effort; 40 percent of the cost is photogrammetry and 60 percent of the cost is cartographic. The photogrammetry costs are fixed. You must have the photogrammetry work; cost cutting should be achieved in the cartographic area. The cartographic side is in many ways a direct duplication of the photogrammetric manuscript plus the addition of annotation. Direct digital mapping allows one to avoid many of the duplication factors between the photogrammetry and cartographic functions.

For example, the compilation of structures is a labor-intensive effort both in the standard manual photogrammetric process and the cartographic process. On a very dense urban 1:1,000 scale map sheet, the compilation of structures could easily take 16 to 20 hours to complete on the stereo plotter, as well as 12 to 16 hours to draft or scribe by the cartographer. Normallly, the stereo plotter operator draws the building in pencil on the manuscripts from the aerial photography, using the stereo plotter. Then the stereo operator moves to his plotting table and squares up the structure on the manuscript with his pencil, using two 45° triangles. After the manuscript has been sent to the cartographic section the cartographer either inks or scribes the structures, again using the two 45° triangles. The structures have been drawn three times in this process.

The drawing of structures using a direct digital mapping device can reduce the labor effort significantly. Using standard building software squaring routines, the capturing of structures can be reduced to approximately a total of 8 to 12 hours for a 1:1,000 map. We at TCB Data Systems have written our own offline structure squaring routines that have cut the compilation time to around 4 to 6 hours for a 1:1,000 map. Using various line types and button codes, the computer program can square a building on a given bearing, or by using the bearing of the first two points. The squaring routine can be interpreted to handle odd shapes and then return to squaring the structure. This software routine has handled row houses with over 100 building corners with no problems.

Spot elevations are another very labor-intensive item in both the photogrammetric and cartographic processes. The stereo operator reads and makes an "x" or "+" for his spot elevation, looks away from the eye piece and reads the vertical scale for the elevation on the stereo plotter, and then moves over to the stereo plotter table and writes down the elevation. The operator then goes back to the stereo plotter, moves the dot and reads the next spot elevation, and starts the process all over again. Each time the operator writes a spot elevation on the plotting table, he is losing a certain amount of concentration. After the manuscript is complete, the cartographer goes through the process of redrafting the spot elevation onto the final sheet.

Using direct digital mapping procedures, the stereo plotter operator can find the location, set the elevation dot, and push a button. The elevation and spot symbol is then written on the manuscript in a fixed location. TCB Data Systems has gone one step farther; all spot elevation annotation will be put in the upper right corner of the spot symbol unless the spot elevation annotation conflicts with some other planimetric detail. The stereo operator can, by pushing another button, place the spot elevation annotation in a more appropriate location.

Another area of time saving using direct digital mapping is in the absolute orientation of the stereo models. First the stereo model is relatively orientated by the stereo plotter operator. Then, by guiding and prompting on an alphanumeric or graphic CRT console, the system will take the stereo operator through the steps of absolute orientation. After determining the orientation parameters, all subsequently measured model points are transformed into ground control coordinate systems in real time, without the need of physically leveling and scaling the stereo plotter. Only if required, as in the case of contour lines, etc., is it necessary to physically scale and level the stereo model. In this case, the appropriate orientation elements can be computed.

The above comments have been only a few of the labor savings advantages in the production of direct digital mapping. Let's now examine some of the good of direct digital mapping from the end users' side.

As mentioned earlier, a direct digital mapping system allows for a multipurpose common geographic digital data base. Using a common geographic digital data base, one can add various utility and land information overlays.

Many cities have gone through a period of rapid growth and development but have paid little attention to the day-to-day activities of maintenance to their records. Most city and utility companies records and maps do not clearly show existing and up-to-date utility or planimetric features. There are no clear records of land use, ownership, service address, or utility lines with the material, size, and location.

With a direct digital mapping data base system, maintenance becomes less of a problem. TCB Data Systems has estimated that ten digitizer operators/engineering technicians will be able to maintain and keep current the complete City of Houston data base system, compared to over fifty draftspersons and engineering technicians now trying to keep the system current.

A complete digital mapping system can act as a data management tool for the decision makers of the organization. Data management is a major element in the daily functions of an organization. A direct digital mapping/data management system can yield the following advantages.

- The data are retrievable, element by element, as the user might require to address different needs; i.e., the user only needs to view data pertinent to his problem.

- The system allows real time access to the data and is dedicated to this single purpose.

- The system and its data are available at the location within the organization where it is to be used.

- The system has a very high degree of security to maintain the validity and the resulting high degree of reliability of the data base.

- The system is expandable to accommodate the needs of new users, new data, and additional needs of the original users.

- The system possesses the ability to easily update data and assure the immediate use of the updated data.

Economic feasibility is a necessary ingredient in justifying the adoption of direct digital mapping. TCB Data Systems has completed a benefit-cost study for the City of Houston Department of Public Works. The study was to quantify and compare the benefits and costs of the Metropolitan Common Data Base (METROCOM) system. The quantifiable benefits exceeded the system costs, producing a benefit-cost ratio of 3.32:1 with a two-year payback. These numbers do not include the intangible benefits of greater employee productivity and job satisfaction, higher morale, and goodwill.

The above references of the good of direct digital mapping are only a few of the numerous reasons for direct digital mapping. Let us now examine the "bad" and the "ugly."

The bad of direct digital mapping can be broken down to three areas: hardware/software, data entry, and data retrieval.

Hardware is going to break down. You can count on 5 percent of the time some part of the computer or some peripheral device associated with the computer will be out of order and in need of repair. TCB Data Systems strives for a 92 percent, or better, computer-up time. The computers are too often blamed for many of the everyday problems that occur. Computers do not make mistakes; computers are obedient; computers do what they are told, however stupid the instructions.

The hardware/software vendor will tell you his system can do building squaring, centerline expansion, polygon clip, scissoring, snap to, crosshatching, stream digitizing, parallel line entry, etc. Yes, the system can do all of the above, but the question then becomes, "How efficient are those features advertised?" Remember the hardware/software vendor is not in the business of production, he is selling a system. There are heavy requirements on the system to do some of the above tasks which are, in most cases, very time-consuming. As a user of a system, there is often a need to work around some of the gimmicks that the hardware/software vendor offers. Use the hardware/software system to perform those things it can do most efficiently.

As for software, remember that the software from these vendors, or even your own, is not complete, nor will it ever be. There is not a hardware/software system that has all the answers, no matter what the vendor salesmen may say. No matter how great and efficient the software is, the software will, in most cases, not satisfy your needs. You will want additional software, or revisions to the current programs, for your own applications or the next job.

Whatever system you have or plan to acquire, allocate some time for program development. It is the user who must take the existing hardware/software package and build user tasks to make the input and output of direct digital mapping data more efficient and useful.

An example of one of the features offered on most direct digital mapping systems is polygon clipping and scissoring. When you envoke this series of calls and begin entering data, every single line segment or symbol you add to the system must be checked by the computer to see if the line or symbol falls within the predefined polygon before the element is stored in the computer. This checking process can use up much of your computing power, especially if you are entering lines, such as contours, in a stream mode. If you feel you need polygon clipping and scissoring, then use this feature as an offline background task after the data have been entered.

As you begin using direct digital mapping systems, there will be some resentments and doubts about the system on the part of the operators using the system. Most operators starting to work with a direct digital mapping system have never worked with a computer before and are afraid of the equipment. The operators often see the system as taking away their jobs in the near future.

Operators are hesitant to use new tasks and operations which are different from those they have been using in a manual system. As mentioned earlier concerning TCB Data Systems' building squaring routine, the stereo operators have been hesitant to use this routine, because they cannot see exactly how the building is being drawn at the time of compilation. The operator would rather use a macro (a small computer program) that squares the building on the manuscript or on the CRT screen as he is drawing the buildings. Unfortunately, this online process is very tedious and time-consuming.

Contours are one of the biggest problems in direct digital mapping, from both an input and output mode. Some of the problems with direct digital contours are as follows.

- Contours take up a lot of file/storage space on the disk packs.
- When drawing contours directly it is difficult to start or close a contour to a line segment.
- Most stereo operators cannot draw cartographically pleasing contours using direct digital method.
- Due to the file size, edits and corrections take more time.
- Display or plotting contours, due to the volume of data, take a long time.
- Contours on steep embankments and at a very close interval may tend to cross at times.

If, after reviewing the above problems, you decide you still need contours captured direct digitally, you need to look at the alternatives. What are the contours being used for? In most all cases, photogrammetric contours are used as a planning tool, not for design. If the contours are for planning purposes, then why not use digital terrain modeling programs for your contours. This gives you more flexibility for portraying your contour data. A series of x, y, and z values can be easily extracted to create plan and profile views. Values x, y, and z can be used to produce perspective views and volumetric computations. Contours, as lines, are more difficult to achieve using the above process.

The output of direct digital mapping is not as pleasing to the eye as manually scribed maps unless you are using a photo head plotter.

Ink plots on mylar are a real problem on almost any plotter. Having worked with several different plotters over the last 15 years, the problems tend to be the same.

- Pens dry up in the middle of a plot.

- Pens drag, giving extraneous lines.
- Blobs of ink appear in the plot as the pen starts to draw a line.
- Limited numbers of line widths are available using ink pens.
- Pens wear out very quickly.

The output of direct digital mapping leads into the "ugly"-- the proposed client. The proposed client is an individual or organization that does not truly understand the complexities of direct digital mapping.

The proposed client may expect the cartographic standards of a manually drawn, cartographically adjusted, scribed map sheet, not ink-on-mylar with only three pen sizes that is not necessarily cartographically pleasing.

The proposed client may want additional information and data added to the data base that is undefined now, but will be defined by the middle of the project. Naturally, these data will be added to the data base at no additional cost to the client.

The proposed client may ask for a digital map to be delivered to him on a magnetic tape to be loaded onto his system. The proposed client's system is to be determined at a later date.

Recently, as an example, a proposed client asked for a bid at a fixed price with these specifications.

> The contractor will produce direct digital mapping for 16 square miles of high-density mixed use urban area to be specified later. The supply of the maps will be at a scale of 1" = 40' and the aerial photography will be 1" = 400'. The direct digital mapping will be done using an Analytical Plotter and you will capture all visible and relevant data. This is all to be done within six months.

How can a firm give a good cost estimate as well as meet the needs of this client with these kinds of specifications?

Many of the problems with the client could be eliminated if the client knew what he wanted. For a successful digital mapping project, a plan consisting of four phases is recommended. The first phase is primarily a study phase, for which a detailed outline is given below. The second phase would follow directly from the first phase and includes data base definition, developing a data base for a pilot area, selected application implementation and testing, and the determination of an estimated cost of developing the complete data base. The third phase includes the development of the entire data base, and the development of application programs designed to use the data in the data base, and other related activities. The fourth and final phase is primarily a maintenance phase.

The first phase consists of reviewing general planning, mapping, informational, and user requirements.

This is done by producing a list of personnel to be interviewed, including management personnel, planners, engineers, surveyors, cadastral, computer services, and drafting personnel. The interviewing of these key personnel will determine the major objectives in seeking to establish a digital mapping program.

As these interviews are completed, they will be analyzed to determine the following.

- The type, amount, currency, and quality of data available from each major source.
- The current format of the data, including its availability in machine readable form.
- Interest in a digital mapping system on the part of sources contacted and the specific focus of that interest.

During this phase, the digital mapping system would be designed along with a program and strategy for its implementation. The objective is to develop a detailed design for the digital mapping system and a plan for its implementation. It should be noted that the full development of a system is an iterative process where, as the system develops from general concept through detailed design to actual implementation, each step would result in the modification of prior concepts and procedures. This iterative process will allow the data base designer to make needed corrections and prevents a large investment of resources in programming procedures ultimately not required or inappropriate.

The elements that should be included in a Request for Proposal (RFP) for interactive graphics system procurement must be defined. Some of the items to be considered when selecting a digital mapping system are as follows.

- The system must allow for real-time access to data and be dedicated to that single purpose.
- The data must be available at the location within the organization where it is used.
- The system should incorporate an indication of the confidence level associated with various data elements to allow the user to determine the acceptability and reliability of data for his application.
- The system should relate not only to specific polygons but should also have the capacity to produce data for broad geographic areas. The system should also be able to relate to line segment data.

- The data should be stored to allow easy retrieval of information, to safeguard against distortion, and to not interfere with the CPU operation. Also, for security against loss or damage, data software programs and system specifications should be duplicated and kept in safekeeping at a number of different locations.

- Changes to the data base in each satellite system must be so linked to the data base to enable its master files of polygons, line segments, and addresses to be periodically updated. The updated data should be made available for immediate use.

A small number of vendors should be selected to perform benchmark demonstrations and prepare a benchmark package. (The benchmark package is a definition of demonstrations to be performed by a vendor during a typical two-day benchmark.) The benchmark package would include a representative sample of data and instructions to the vendor. Then evaluate the vendors and select the system which best meets your requirements.

A work plan for system installation must be developed. This plan would include a determination of building modifications, air conditioning, power requirements, training, scheduling, and other functions necessary for a successful installation.

During this phase, a budgetary estimate for the development of the entire data base must be prepared. However, accurate costs for developing the complete data base will not be determined until a pilot area data base is developed in Phase 2.

A short summary report, including the following, should be prepared prior to beginning Phase 2.

- A discussion of available maps, documents, data files, and aerial photography. Included would be an analysis of their suitability as sources of information for input into the data base.

- A discussion of current manual procedures for producing, updating, and using maps.

- A summary of information from the interviews and a definition of general data base requirements.

- A system configuration plan for the system purchased.

- A discussion of the rough budgetary cost estimate for building the data base.

- A definition of work to be performed in Phase 2.

- Estimated costs for Phase 2.

Phase 2 includes the following activities.

- Definition of the content and structure of the data base.

- Definition and development of system tables, user commands, techniques, and procedures required to build a pilot area data base.

- Selection of a pilot area and building a data base for the pilot area. This will provide several significant benefits, among them an ability to

    - test and refine the data base design.

    - test and refine system tables, user commands, and data entry techniques and procedures.

    - demonstrate the content and uses of the data base.

    - allow an accurate determination of the costs of developing the complete data base.

    - test the practicality of including different types of data in the data base.

    - implement selected applications on the system and evaluate implementation success and effect on system performance.

    - conduct systems application, mapping, and other user training appropriate to begin system operations.

Phase 3 includes developing the full digital mapping data base and the development of any application programs.

Phase 4 includes training to operate the system, updating the data base as required to maintain the currency, and developing specific application programs.

This type of program of planning and implementation of your project will eliminate many of the problems of client-vendor relationships

THE GRAPHIC DISPLAY OF INVENTORY DATA

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ABSTRACT

This paper distinguishes two mutually contradictory purposes for a regional information system: parcel classification and regional inventory. These two purposes ask different questions, call for different sampling and data storage procedures, yield different degrees of error at a given scale of analysis, and, most importantly, require different kinds of map display. An accurate classificatory system, with its focus on the dominant land uses within each data cell, will inevitably miscalculate regional totals. A valid inventory system, with its use of regular or random point sampling, will inevitably misclassify individual parcels of land. Inventory data are thus not appropriate for classificatory purposes such as tax assessment, land-use zoning, or prime-lands designation. It follows that inventory data should not be mapped in a way that allows identification of individual landholdings. This paper suggests three ways to map inventory data without inviting classificatory misuse: overlapping legend categories, probability blocks, and probability isolines. The selection of appropriate map techniques is a systems responsibility: the information system software should automatically adjust its graphic output to match the resolution and sampling logic of the input data.

INTRODUCTION

The story is perhaps too familiar. It begins with a request for a "reconnaissance study" of some resource -- prime farmland, forest volume, mineral prospects, wetlands, whatever. The project is an attempt to gain a general overview of the present state of a resource; for the purposes of this discussion, let us say that the study is supposed to determine the amount of prime farmland in the vicinity of an expanding metropolis. The objective is laudable, but the budget is small, and the result is a typical compromise between ideal research design and permissible cost. The constraints force us to gather data by some form of sampling rather than by a detailed survey. For a general picture of a resource, the sampling compromise is acceptable if the users are aware of its limitations.

The story, however, does not end here. The data are geocoded, stored on disk or tape, massaged by the computer, and finally output in graphic form for publication. The report is presented to the public, usually at a staged hearing with slides and a gallery of maps hung on panels around the speakers' table. During an intermission, the audience mills about, suitably impressed by the display, and then the balloon deflates: a few individuals crowd forward and peer intently at small parts of the maps. "They've got my back forty shown as swampland -- won't my cows be surprised!" "There hasn't been any timber on the Farley place since the War!" "Look, this map shows . . . " One by one, they find "mistakes" on the maps. The murmur spreads, and the audience after the intermission is more skeptical and much less receptive than before the close look at the maps. Their credibility is strained, and if the strain is too great, we may face a classic baby-with-bathwater situation as a valuable reconnaissance study is rejected along with the ill-conceived maps.

To repeat, the story is perhaps too familiar. The question is, what is the underlying cause and what can we do about it? We cannot accept the idea that the problem is merely ignorance on the part of the uninformed. That idea is seductive, but certainly too easy and probably wrong. A more likely culprit is the failure of many resource studies to distinguish between two mutually contradictory purposes of a resource information system: parcel classification and regional inventory. In this paper, we will do three things:

1) briefly describe the logical differences between regional inventory and parcel classification;

2) summarize some research on inventory and classification error rates; and

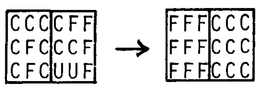
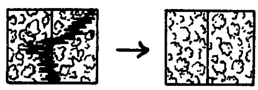
3) suggest ways to display inventory data without inviting classificatory misuse.

INVENTORY AND CLASSIFICATORY LOGIC

An ideal resource information system would grid the earth at half-meter intervals, storing instantly retrievable data on each tree and rock outcrop and intermittent waterway. Such an information system would allow the user to describe the resources at any specified location with a high degree of precision. It would also lend itself to very accurate regional inventories; the forest wealth of a county, for example, could be determined by counting trees in the computer memory.

In the real world, however, we can neither gather nor handle such a large volume of data, and therefore we are forced to choose between parcel description and regional inventory. These two end purposes of an information system are often incompatible because each has its own rules of sampling and data storage. In addition, the two require different kinds of map display, which is the substantive point of this paper. To make the distinction between the two types of logic as sharp as we can, we compare the two approaches point by point in Table 1:

TABLE 1. COMPARISON OF INVENTORY AND CLASSIFICATORY LOGIC

	REGIONAL INVENTORY	PARCEL CLASSIFICATION
Question being asked	How much resource X is in area Y ?	What is the resource in parcel Z ?
Typical answers	Area Y has 872 acres of mature forest. 21% of area Y is pastureland.	Parcel Z is a dense stand of pole firs. Parcel Z is mainly class II cropland.
Data type	Quantity measurement (ratio data)	Category assignment (nominal data)
Data cell* coding procedure	Each cell* is tabulated on the basis of the resource at the center (or some random point) within the cell.	Each cell* is categorized on the basis of the areally (or economically) dominant resource within the cell.
Trying to maximize	Statistical validity in the aggregate	Descriptive accuracy in the particular
Willing to sacrifice	Proper description of individual landholdings	Tabulation of small or odd-shaped resource areas
What can (often does, even should) happen	Sample point hits a tiny woodlot in a large open field and records the entire field as forested. 	Narrow alluvial bottomland is lost from data record because it is too small to dominate any data cells. 
Ideal procedure	Use enough sample points to make a valid estimate of even the least abundant resource.	Use small enough cells to keep them homogeneous for even the smallest resource areas.
Real-world compromise	Use sampling theory to limit error for major resources.	Use cell size that can capture most major resources.
Inevitable corollary	Inventories misclassify parcels.	Classifications miscalculate totals.

*The innocuous little word "cell" is the root of much confusion: it connotes, for a given discipline, some unique but vague blend of computer memory address, map location, grid intersection, sensor pixel, cadastral unit, or real-world observation site.

AN INHERENT INCOMPATIBILITY

A careful analysis of the premises and results of the two kinds of logic leads to an inescapable conclusion: if the data cells are larger in any dimension than the smallest homogeneous landscape units, the two approaches cannot be reconciled. A valid inventory system must inevitably misclassify individual parcels of land. Likewise, an accurate classificatory system must inevitably miscalculate regional totals. Reread those two sentences, please; they are the crux of the argument.

Several theoretical and empirical studies have shown that classificatory errors tend to grow much larger than inventory errors as data cell size increases (Figure 1; see also Wehde, 1979). For this reason, a cell or polygon that is far too large for accurate parcel classification may still yield acceptable regional inventories. Herein lies the root of the problem described in our introduction. Most resource information systems are proposed and justified (and therefore funded) for generalized inventory purposes. As such, they are valuable planning tools, but their inventory logic and coarse cell size renders them prone to serious classification errors. It follows, then, that inventory data should not be mapped in a way that allows identification of individual landholdings. Nor should inventory information be made available for zoning, tax assessment, prime lands designation, or corridor selection without explicit safeguards, preferably in the form of mandatory field checking (Yanggen, 1979).

Our track record on this score in not reassuring. In general, our maps have been SYMAP-type printouts or raster plots made directly from the data stored in the computer array (Nichols, 1975). The maps usually contain as much detail as we can show at the scale chosen for publication (Sometimes, we even use sophisticated software to recode coarse data cells or polygons into finer and more precise pixels, usually on the premise that such a procedure allows us to "capture" a map shape more accurately; that was the gist of the misguided criticism in Tomlinson et. al., 1976). Individual landholdings on these lineprinter maps are easy to identify, and our safeguards have generally consisted of vague legend notes about scale and generalization. In effect, we have been committing the informational equivalent of putting a turbocharged V-8 engine in a golf cart, with nothing more than a label on the dashboard to warn the user that the graphic power is too much for the data chassis.

A PROPOSED SOLUTION (OR THREE)

As we see it, the major remaining task is to find a way to display inventory data safely: to show the general pattern of a resource without specifying anything about individual landholdings. The problem is like that of a meteorologist, who knows that the air today is generally unstable, and therefore scattered thunderstorms are probable throughout a given region, but the data simply will not allow a yes-no prediction for a particular place within the region. The

ERRORS IN REGIONAL INVENTORY AND PARCEL CLASSIFICATION WITH DIFFERENT SIZES OF GRID CELLS

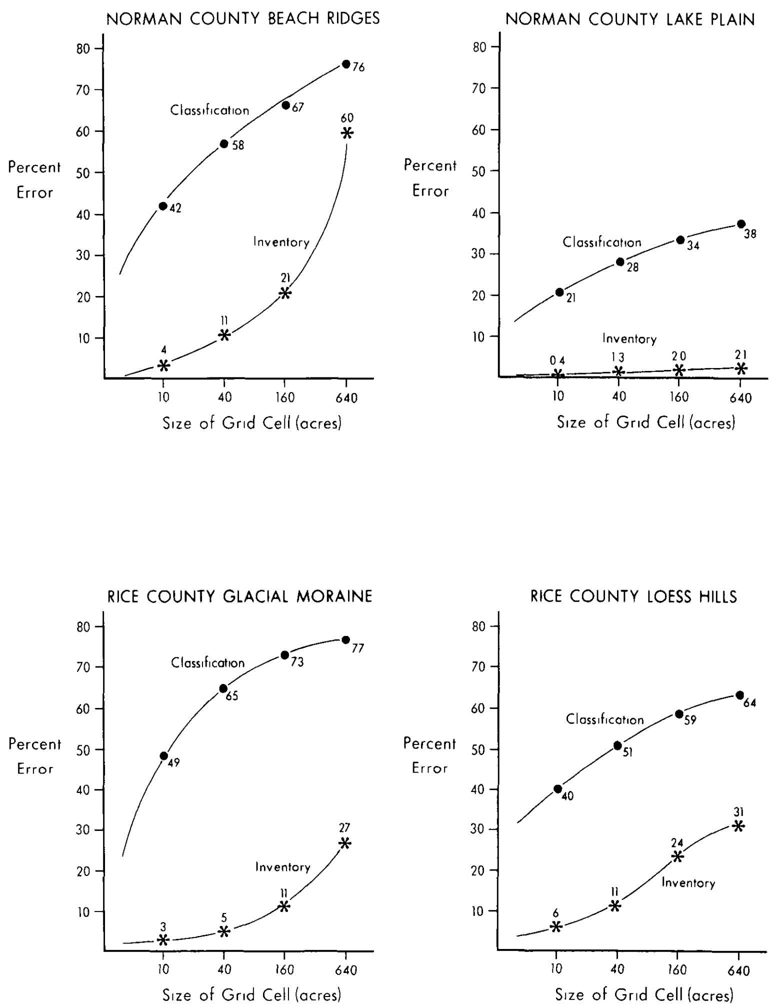


Figure 1. Inventory and classificatory errors in coding soil information from four representative Minnesota soil landscapes. "Percent error" is defined as the percentage of 2-acre polygons (digitized from the detailed County Soil Survey) that were miscategorized by the classificatory approach or were over- or under-estimated in the aggregate by the inventory approach (from Gersmehl and Napton, 1982).

conventional solution -- to report the probability of precipitation in percentage terms -- is reasonably well understood and widely accepted by lay people and experts alike. A similar approach should be equally useful in resource cartography. Operationally, this idea can take several forms:

Overlapping legend categories. The simplest way to show the uncertainty is to recode the map legend into overlapping or non-specific categories. Rather than using discrete and exclusive groups (like 0-10, 11-20, 21-35, etc.), we can adjust the group boundaries to reflect the degree of uncertainty (e.g. 0-18, 7-26, 16-35, etc., or Groups A and B, where A is 0-10 and B is 11-20). This approach makes it impossible to rank two parcels of land solely on the basis of the map, but it suffers from one fatal weakness: real-world variability of phenomena such as soil productivity or forest volume is often extremely great even within a small area. An accurate set of category boundaries to describe the land in a given small area can be nearly as wide as the entire range of variation throughout the map. The resulting map categories (e.g. 0-34, 4-35, 6-36) are not very helpful in communicating real patterns and differences in the region. Conventional statistical measures such as means and standard deviations may help, but they are both time-consuming and rather forbidding for lay readers.

Probability blocks. The second way demands a bit more computer time, but it preserves the essential traits of the natural landscape quite well. The process makes use of a "moving window," a widely used method of scanning and recoding data in a geocoded array.

The conventional use of a moving window is as a noise filter, to simplify a remotely sensed image by determining the majority type in a local area (Lillesand and Kiefer, 1979, pp. 573-577). The input to the process is a cluttered patchwork of small cells. The operation is a sequential placement of the "window" on a regular grid superimposed on the base; the window typically exposes a number of cells (say 25, for a 5-by-5 window) that are then classified and counted by type. If 16 of the 25 cells within the window at a given placement are of a particular type (as in the window shown on Figure 2), all cells within that window would be reclassified as that type. The output is a simplified map in which each windowed block is shown as a uniform expanse of whatever type dominates the most small cells within the window at each placement (Figure 2 left). A conventional moving-window procedure thus loses a great deal of information.

The right side of Figure 2 shows a variant of the moving-window technique, in which the windowed blocks are recoded by classifying each block according to the percentage of small cells in a given category. In this case, the output would be a series of rather coarse choropleth maps showing percentages of occurrence within blocks rather than actual occurrence within cells. The class boundaries, of course, can be changed or even omitted in favor of an unclassed map (Tobler, 1973; Brassel and Utano, 1979). The key idea is that the inevitable uncertainty at the scale of an individual data cell is masked by merging cells into larger blocks.

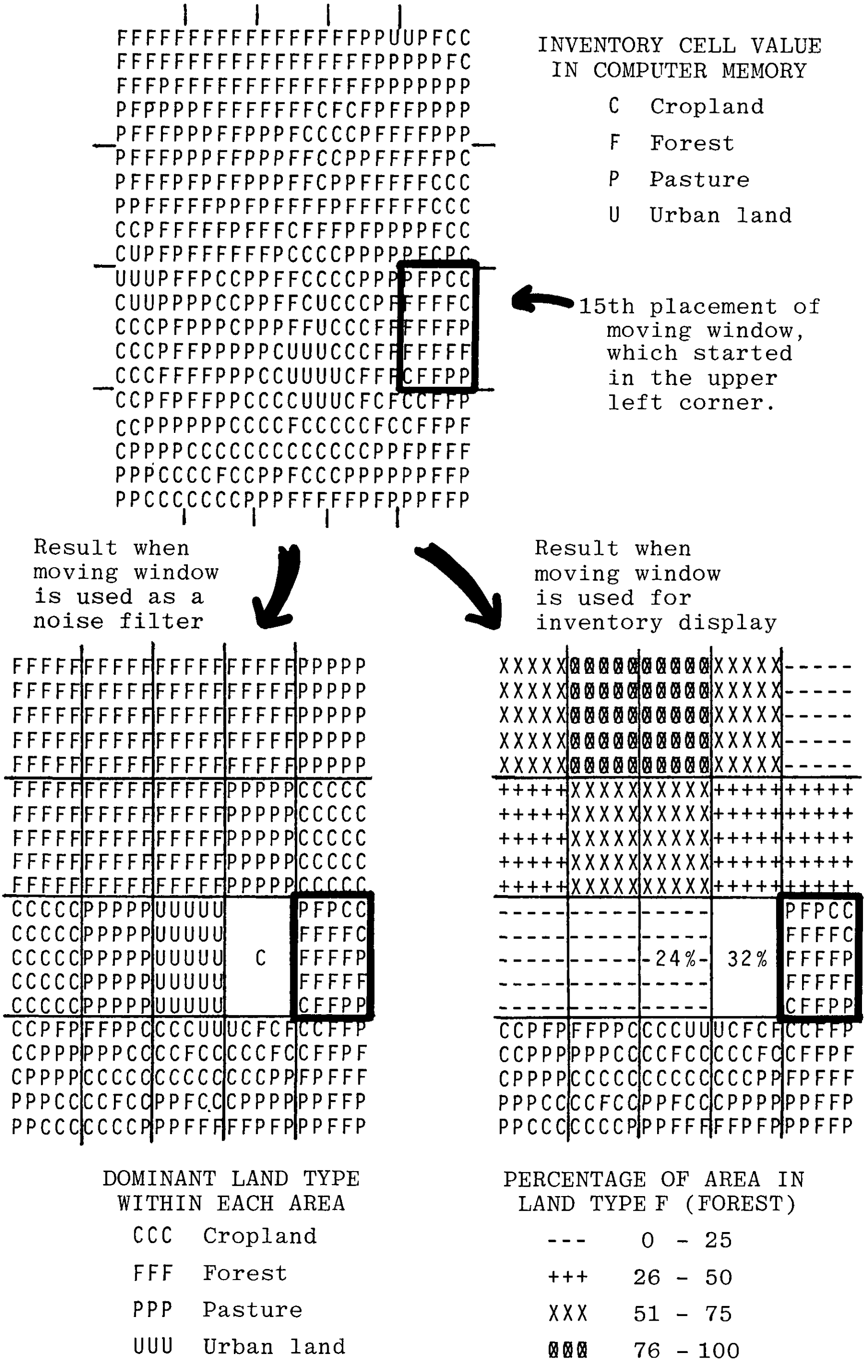


Figure 2. Two uses of a moving window, as a conventional noise filter (left) and as a tool to make probability blocks from inventory data (right). Figure 3 uses the same data.

These blocks, in turn, are keyed to a legend that talks about probabilities of occurrence of a particular trait somewhere within a large area, rather than about the actual value of a given cell. (Yes, we can hear the screams: "Why should we give up so much precision of location?" The answer is simple: if the data were gathered for an inventory (i.e., using point sampling), we didn't really have that degree of precision in the first place. Although we have a value stored for each small cell, the cell value is part of a statistical sample, not a place classification.)

Probability isolines. One of the drawbacks of the block approach is the coarse appearance of the window map, with its staircase boundaries and abrupt pattern changes. The maps are valid, in that they do not imply any more spatial precision than is warranted by the data, but readers may feel that they look too crude for their price tag. This is basically a PR problem, but it is a real one and must be addressed. Even so, we must emphatically refuse to condone a return to a fine-resolution graphic display for purely aesthetic reasons. Our third approach is just a way to "dress up" the probability blocks in order to produce a more impressive display. The method consists of three steps:

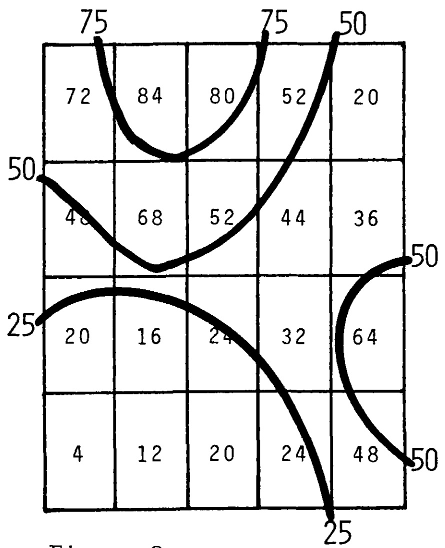


Figure 3

1) Calculate the percentage of a category (say forest) in each window placement as for a block map.

2) Assign this figure to the central cell of the window.

3) Use these figures as control points for an isoline map.

The isoline map, of course, could be shaded or colored in the conventional manner; the legend would say something like:

"Percentage of forest in an arbitrarily selected 10 square kilometers:"

The moving-window isoline method, like any powerful cartographic transformation, should be used with caution. The size of the specified arbitrary area depends on the size of the window, which in turn should be chosen to screen out the minor kinds of repetitive variation in the data. The growing literature on spatial autocorrelation and image processing can provide the basis for a software algorithm to select an appropriate size and geometry for the moving window (Campbell, 1979). Suffice it here to note that the problem is much more complex than implied by standard sales department assertions ("It provides output at any scale you want").

CONCLUSION

Most planning-related information systems were justified as regional inventory tools. To be cost-effective as well as accurate, a resource inventory should generalize from some kind of point sampling method (Lund, 1981). Such a procedure is fundamentally incompatible with an alternative use of the data, namely the classification or evaluation of individual parcels of land. Data gathered for resource inventory will inevitably contain many land-parcel classification errors. Ideally, the primary output for an inventory should be a histogram; straightforward lineprinter maps of the stored cellular data are simply not appropriate for inventory logic. However, the pressures to produce some kind of "general" map are very strong, and indeed the data can yield a generalized picture of a resource distribution. The probability-based techniques described in this paper will allow the display of general patterns without revealing the possible inaccuracies at the scale of individual cells.

We are not offering a new technique -- indeed, it has been used for many years by a number of agencies (e.g. the U. S. Soil Conservation Service, for its county association maps, and the Canada Land Inventory, for its land suitability maps) What we are proposing is that the techniques used on these manually drawn maps should be made a mandatory part of most automated resource cartography. In other words, we think that the graphic display should be compatible with and should clearly communicate the underlying logic of the information system and the degree of generalization in the data.

It is fashionable among systems analysts to refer to scale and resolution as "data problems." To paraphrase several presentations on the subject: "Of course, we still have a data problem. Until the field people give us data at a sufficiently fine resolution, we will not be able to eliminate some of the errors you noted on our maps." We beg to differ. Scale incompatibilities will always plague a study that considers more than one environmental trait or variable. The inability to sense the logic, precision, and resolution of input data, and to adjust the output accordingly, is a <u>systems</u> problem (not a data deficiency). A method of displaying inventory data without inviting classificatory misuse should be built into any public resource information system.

POSTSCRIPT

We have demonstrated a fundamental incompatibility between two kinds of information systems, one designed for regional inventory and the other for parcel classification. It is logically and should be legally indefensible to use an inventory-based system for any classificatory purpose: tax assessment, prime-lands designation, zoning, or corridor selection. Although we did not address classificatory purposes directly in this paper, we do want to emphasize that they demand an information system whose sampling logic and scale of resolution are appropriate to that end use.

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AN INTEGRATED SPATIAL STATISTICS PACKAGE FOR MAP DATA ANALYSIS

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ABSTRACT

In the analysis of geocoded statistical data, common practice has been to treat the data in isolation from its locational or spatial characteristics. This results in a potentially critical loss of the spatial information that is contained in the mapped representation of the statistical data but not in the application of aspatial statistical techniques such as cross-sectional regression. One explanation for the domination of aspatial methods is the absence of an integrated software package to carry out explicitly spatial data analysis on geocoded databases. In this paper we describe the functional elements of such a package, based on our development of a typology of general-purpose statistical map data analysis needs.

The design of the integrated spatial statistics package includes a module for transforming digital coordinate data (e.g. polygonal boundary files) into concise mathematical representations of relative location for use in the analytic procedures. We distinguish between several categories of locationally-referenced data including point patterns, point-sampled data, grid-cell data, irregular polygon-based data and network and flow data. Within these classes we consider a hierarchy of spatial analytic objectives: quantitative pattern description and randomness testing, univariate modeling, spatial interpolation, space series analysis, multivariate spatial analysis, spatial forecasting and control, and dynamic and space/time analysis. Examples of the application of the package to typical spatial statistical problems are discussed, with emphasis on the hierarchial nature of the analytic process.

INTRODUCTION

The growing acceptance of the concept of a geographic information system or a spatial data handling system reflects the realization of the uniqueness of spatial data. This uniqueness has motivated the search for input techniques, data structures, and query languages appropriate to spatial data processing. These specialized resources are integrated within a geographic information system to provide the capability to enter, store, retrieve, manipulate, and display spatial data.

An additional function included in most detailed definitions of geographic information systems is spatial data analysis. In contrast to spatial data manipulation or massaging, spatial data analysis is usually defined as the process of deriving useful information from the data as opposed to realligning or transforming the data. In addition, the goal of analysis is the interpretation of the derived results whereas the goal of manipulation is the attainment of data in a form more suitable for subsequent storage, display, or analysis; that is, data manipulation in itself does not normally produce information that is useful in problem solving.

The analytic components of existing systems contain diverse capabilities. In part this pluralism reflects the variety of applications and problem areas that geographic information systems address and the wide variety of analytic tools that may be appropriate for specific applications. Nevertheless, a small set of generic analytic tools are common to many geographic information systems - these include simple measurements such as the length of line segments and area of regions, polygon overlay, point-in-polygon determination, and perhaps some form of spatial interpolation and contouring. This existence of a defacto set of generic spatial data analysis functions suggests the possibility of developing a scheme for classifying analytic functions and identifying, for a particular application, those that may be appropriate to include in a particular geographic information system.

A category of spatial data analysis that has been largely ignored by designers of geographic information system is statistical spatial analysis. When statistical techniques are included at all in a system (perhaps through linkage to an existing package of statistical methods), they are nearly always standard, aspatial techniques. The use of these techniques to analyze spatial data always results in a potentially significant loss of information and sometimes results in misuse of methods due to the violation of assumptions normally not met with spatial data. To paraphrase Tobler's analogy (Tobler, 1980), the use of aspatial techniques - e.g. regression analysis - on spatial data is akin to arranging monthly time-series data according to the alphabetical order of the months and then analyzing it. The availability, in a geographic information system, of precise digital descriptions of location along with attributes of those locations, provides an ideal opportunity for making use of truly spatial analytic tools.

The purpose of this paper is to present a preliminary functional description for a general purpose statistical spatial data analysis element that could be included, in part or in whole, in a geographic information system. This functional design is based upon an attempt to identify the various classes of spatial data analysis. Following the functional description, a brief example of the application of some of the tools discussed is presented.

A TYPOLOGY OF SPATIAL ANALYSIS FUNCTIONS

There are many alternate approaches that can be taken to identify and classify statistical spatial analysis functions. For effectiveness and simplicity of presentation, an approach based on a classification of statistical and spatial data types will be used. Three types of spatial data are portrayed on maps: point, line (or network), and area. In addition, three major levels of measurement for statistical data exist: nominal (presence/non-presence or binary), ordinal or rank, and interval/ratio. The combinations of spatial data type and level create the need for alternative statistical map types. For example, a dot map may be used to graphically depict the spatial pattern of nominal-level point-located phenomena and a graduated point symbol map used for ratio-level point-located or point-sampled phenomena.

The cross-classification of spatial data by level of measurement and spatial dimensionality yields nine major categories. For the purposes of this paper, rank-ordered data is not considered as generating substantially distinctive spatial analytic requirements and is therefore considered together with the ratio-level data category (although some specialized spatial analytic tools have been developed for rank-ordered data: see, for example, Glick 1982).

In addition to the definition of classes of spatial data to be used in statistical spatial analysis, a hierarchical categorization of generic types of analyses is possible. For example, at an initial problem solving stage, information can be extracted individually from single-variable statistical maps. We refer to this as univariate spatial analysis. In the bivariate or more general multi-variate class of analysis, the relationship between two or more statistical maps is investigated. Finally, map data may be used to generate new maps; for example, maps of future conditions or maps covering areas where empirical data is not available. For lack of a better lable, we refer to this category of analysis as spatial forecasting.

Univariate Analysis: Nominal Data

Three fundamental objectives of univariate statistical spatial analysis are to provide: 1) concise descriptions of important spatial aspects of the mapped data; 2) inferential tests related to the descriptive measures; and 3) modeling of the spatial variation in the data. As shall be discussed in more detail, these three goals can be viewed as steps in an iterative process for deriving quantitative information from mapped data.

Point Patterns - The analysis of nominal-level point data (i.e. point pattern analysis) is relatively well-developed methodologically - probably due to its application in a wide variety of disaplines including plant ecology, geography, archeology, and geology. A wide range of descriptive measures are available, some of which provide useful descriptive information but do not interface well with follow-on statistical analysis procedures. For example, the well-known centrographic measures such as the bivariate median and standard distance (Bachi, 1963) are useful in some applications but lack a strong connection to inferential testing and model-building.

Among the more popular and useful measures are distance-based measures (e.g. nearest-neighbor distances) and quadrat or cell-count measures. Many refinements of the original work in these areas have been and continue to be made. Good references that describe these measures and their relative strengths and weaknesses are available (e.g. Rogers 1974; Ripley 1981). Polygon techniques, in which the spatial point pattern is transformed into a polygon structure (usually based on a Thiessen or Delaunay polygon approach) can also be used to produce descriptive measures of a point pattern (Boots, 1974).

The distance-based, quadrat count, and polygon-based measures can be used in hypothesis-testing due to their connection with theoretical statistical models of spatial variation. For example, the simplest and earliest distance based measure, the mean distance between nearest neighbors, has an expected value of one-half the square root of the density parameter for the region under study. This expectation is based on an underlying two-dimensional Poisson process - a process that is commonly used as the baseline independent random mechanism for placing points in the plane.

This connection of measures of spatial point patterns to theoretical random processes of point allocation immediately suggests the most fundamental of inferential tests on spatial patterns - randomness tests. The purpose of a randomness test for a spatial pattern is to evaluate the possibility that the points are spatially distributed such that the location of other points has absolutely no bearing on the location of a particular point. Thus, if the null hypothesis of randomness cannot be rejected, the conclusion is that the pattern could have been generated by the planar Poisson process.

The distance-based and quadrat methods can also be used to test the liklihood that an observed spatial point pattern could have arisen from a particular non-random generating process. Models of both clustering and more-regular-than-random processes exist (see Getis and Boots 1978) and inferential tests have been employed to assess the liklihood that an observed pattern could have been generated by these processes.

If a generating model can be identified for a point pattern it is possible to estimate the parameters of the model. The estimated model can then be used as a concise description of the spatial characteristics of the observed phenomenon, as a source of interpretable information about the possible mechanism that has produced the pattern, as a basis for forecasting.

Line Patterns and Networks

The statistical spatial analysis of nominal one-dimensional or linear data is much less developed than for point or area data. In this case we have a linear pattern in space and the goal is to attain information on the locational aspects of the pattern. Independent random generating processes, analogous to the Poisson point process, have been suggested for generating a random pattern of straight lines in a plane (e.g. Bartlett 1975). Applications for this approach include the testing of the randomness of line transects in spatial sampling situations.

Many descriptive measures exist for assessing the geometric and topological attributes of networks. These include measures of circuitry, connectedness, redundancy, and hierarchical structure of the network. In addition, we can measure the complexity of line segments and determine bifurcation or branching measures, etc. When a network is represented (with attendant loss of information) as a connectivity matrix of modes, the measures and methods of graphtheory provide a powerful analytic methodology (Christofides 1975). The application of statistical inference and modeling in network aralysis has been undertaken by geomorphologists and hydrologists interested in the statistics of the topological properties of stream networks (Haggett and Chorley, 1969).

Area/Polygon Pattern

Nominal area data can be represented as simple polygon outline maps. One set of descriptive measures related to this class of spatial data are those used to describe the shape and form of areal features. Shape measures are numerous and range from highly simplified one-parameter indices to complex representations containing information on boundary complexity, compactness, and directional bias (Bookstein 1978; Mandelbrot 1977).

Analysis may also be carried out on the polygon net or tesselation of the plane taken as a whole. Typical descriptive measures are the mean number of polygon sides, mean polygon perimeter, mean length of a side, and mean area of polygons. For Thiessen polygons, expectations for these measures based on using a Poisson point process to generate the polygons, have been derived. Another approach to creating a random polygon net is by partitioning an area by a system of random lines (Haggett et al 1977).

Univariate Analysis: Ratio-Level Data

In nominal-level spatial data analysis, the objects of the analysis are the digital coordinates that define the location of the entity. The ratio-level case takes this data into consideration but also uses the corresponding set of numerical attribute or descriptive data relating to the locational entities.

Ratio-level point data, in many real-world applications, are point samples of spatially continuous phenomena. In these cases it is customary to use the sample points to estimate a continuous surface, as can be represented by isoplethic mapping techniques. In our scheme, methods for carrying this transformation out are considered to be in the spatial forcasting/interpolation category of analyses.

In the special case of points that fall on vertices of a regular lattice such as a square a triangular grid, methods generalized directly from time-series analysis can be used. Thus we have two-dimensional correlograms or spatial autocorrelation functions, two-dimensional periodograms, and two dimensional spectral density functions. These descriptive measures of spatial pattern provide robust and precise information on key characteristics of the spatial data - for example, clustering of similar values, spatial periodicity, major directional biases or non-isotropy and scale effects. Two-dimensional spectral density and autocorrelation measures are also very well suited to inferential testing and model-building (Besag 1974; Ripley, 1981).

Through the use of schemes to define neighboring or connecting data units (i.e. a weighting matrix), the spatial spectral density and autocorrelation methods can be extended to the more general case of irregular data points and irregular polygons (Cliff and Ord, 1973). Thus, for both point and area-based data spatial spectral density and autocorrelation analysis provide tools that support description, inferential testing, and model-building.

There are, of course, many other useful analytic techniques appropriate to ratio-level univariate spatial data analysis. For example, one productive tool appropriate for both regular grid cell data and some irregular polygon data is the analysis of spatial scale variance (Moellering and Tobler 1972). This straight-forward application of nested analysis of variance partitions variance into several user-defined hierarchial levels of grid-cells or irregular polygons.

Table 1 summarizes the categorization of univariate statistical spatial analysis techniques according to data type and measurement level. For linear data, two major classes of methods are network/flow analysis and one-dimensional spatial autocorrelation/spectral density analysis. The various methods for describing and modeling flow patterns in space generally focus on flows through a topological network whereas one-dimensional spatial autocorrelation/spectral density analysis considers the distance relationships along a single transect or straight line.

Table 1: Typology of Univariate Statistical Spatial Analysis Techniques

Data Type	Measurement Level	
	Nominal	Ratio
Point:	nearest-neighbor analysis quadrat/cell counts centrography measures polygon techniques spectral analysis	spatial auto-correlation analysis spatial spectral density analysis
Line:	line pattern analysis network measures graphic theoretical measures	network flow analysis one-dimensional spatial autocorrelation anaylsis

Area:	shape analysis polygon net analysis	spatial auto- correlation analysis spatial spectral density analysis scale decomposition

BIVARIATE ANALYSIS

In bivariate statistical spatial data analysis, the overriding goal is to obtain information on the relationship between two statistical data maps. Two aspects of the study of pairwise relationships, often performed sequentially, are the analysis of the degree of similarity between maps and the analysis or modeling of transformations required to convert an input map into an output map.

The methods available to be used for bivariate spatial analysis largely make use of the descriptive measures discussed in the previous section. Many of the methods are analogous to the standard aspatial statistical methods of correlation and regression analysis. For example, Tobler (1979) has introduced a technique to transform a given input nominal-level point map into a specified output map where each point in the input map corresponds to a point in the output map. This technique, known as bidimensional regression yields information on the spatial pattern of distortion needed to implement the transformation. Similarity of pairs of networks has also been assessed using a variety of correlation-like techniques (e.g. Cummings et al, 1973).

For ratio-level data, the techniques of spatial autocorrelation and spectral density analysis provide a powerful methodology for bivariate analysis. The nature of the relationship between two maps can be investigated using spatial cross-correlation and cross-spectral analyses (Rayner, 1971; Cliff et al, 1975; Bennett, 1979). These methods not only provide information on the overall strength of similarity between two maps but also yield strength-of-similarity estimates at different spatial scales or distance lags. This added insight is significant because two data maps may be closely related at one spatial scale (e.g. regional) but unrelated at others (e.g. local). In addition, it is also possible that spatially-lagged effects exist in the relationship between two maps; that is, the value of the dependent variable at a given location may be related to the value of the independent variable at neighboring locations.

Spatial cross-correlation and cross-spectral density analyses provide tools for a flexible methodology for transforming a known input map into a known output map. This approach, known as transfer function modeling, takes advantage of the information contained in the cross-correlation and cross-spectral functions in order to build a transformation model that includes lagged effects as well as autoregressive effects (Bennett 1979).

INTEGRATED METHODOLOGY: AN EXAMPLE

The methods discussed in previous sections of this paper are not unrelated - in a typical application, they tend to be used in a logical sequence; for example, from description to inferential testing to model building and to forecasting. For the class of ratio-level area-based spatial data, typically displayed using choropleth mapping, a methodological flow outline suitable for implementation in an intelligent automated system can be developed.

The example presented here is based on spatial autocorrelation analysis. The objective is to learn as much as possible about a mapped pattern and its relationship to a second mapped pattern. The basic approach taken is to decompose spatial variation by scale and statistical property. The decomposition is sequential with the residuals from any given step providing the input for a subsequent step until all spatial order or patterning has been modeled and the residuals are indistinguishable from a realization of a Poisson process (Table 2).

Table 2: Flow Outline - Univariate Analysis

1. Choose study area, variable of interest.
2. Preprocessing: For map study area, obtain contiguity matrix, polygon centroids, proportion of shared boundary.
3. Define weighted connectivity matrix (possibly interactively).
4. Obtain spatial autocorrelation function - if trend is suspected continue; otherwise skip to step 6.
5. Model spatial trend and remove (i.e. obtain residuals) (trend - surface models, spatial differencing).
6. Calculate autocorrelation function.
7. Identify and specify neighborhood effects model (e.g. spatial autoregressive, moving average model).
8. Estimate neighborhood effects model and obtain residuals.
9. Calculate autocorrelation function for residuals, test for randomness.
10. If residuals random, stop; otherwise go back to steps 5 and/or 7.

For bivariate analysis, the transfer function approach- based on spatial cross-correlation analysis - is outlined in Table 3. Note that the bivariate method relies on results of the univariate method for the input map. The result of the bivariate method is an estimate transfer function model that describes the input-output relationships of the two data maps.

Table 3: Flow Outline: Bivariate Analysis

1. Select input and output maps

2. Process input map through univariate analysis procedure.

3. Use the autoregressive/moving average model estimated for the input series (in step 8 of univariate processing) to transform output series.

4. Access the residuals of both the input and output series.

5. Calculate spatial cross-correlation function for the residual data.

6. Calculate the spatial impulse response function between the input and output maps.

7. Identify the order of the transfer function model.

8. Estimate the identified transfer function model.

<u>Empirical Example</u>

To illustrate the flavor of a univariate statistical analysis using these techniques, an empirical example using stream-bed elevation data is presented. Because this data is linear, the spatial series can be considered one-dimensional. This makes this illustration simpler than would be the case with two-dimensional data. For example, the autocorrelation functions and spectral functions are themselves one-dimensional. Figures 1 through 7 present the results of the analysis.

CONCLUSION

Spatial data requires specialized analytic tools. Geographic information systems and general-purpose statistical mapping packages would benefit by incorporation of a linkage to a generic spatial analysis capability. It is possible to associate specific spatial data types with particular techniques of statistical spatial analysis. This provides input for developing functional specifications for an analytic component appropriate to a particular spatial data handling or statistical mapping application.

In developing this capability, attention needs to be paid to utility routines to prepare the data for the appropriate methods. For statistical spatial analysis, information on contiguity of polygons, nearest neighbors for points, and connectivity for networks are examples of information requirements. Appropriate data structures can assist in making the derivation or retrieval of this information efficient.

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DESIGN ISSUES FOR AN INTELLIGENT NAMES PROCESSING SYSTEM

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ABSTRACT

An overall systems design approach for a names processing system includes design issues concerning a system configuration, names and spatial databases, and names processing operations (selection, positioning, and plotting). A names processing system requires interactive graphics display, data storage, data manipulation, computer processing, and plotting capabilities. Names and spatial databases require an integrated design with respect to the requirements and goals of names processing. Selection consists of the interactive/automatic retrieval of names and spatial data. Positioning consists of a control structure that integrates automatic multi-method positioning algorithms and a human operator (i.e. map editor) in an interactive processing environment. In the names plotting operation softcopy and hardcopy products may be generated on standard display and plotting devices.

INTRODUCTION

Historically, experimental systems have addressed only parts of automatic names processing, because only parts of the process have been approachable given available technologies. These early systems[1] focused on the names processing operations of selection and plotting, and omitted the difficult positioning operation.

More recently, government agencies (e.g. DMA and USGS) have begun to support the large scale development of spatial databases, digital gazetteers, and the hardware and software necessary for automatic names processing (Schmidt et al., 1982; Caldwell, 1982). In addition, technological strides in computer capabilities and software models have supported attempts that have focused on automating the positioning operation (Yoeli, 1972; Hirsch, 1980 and 1982). Currently, all the components of a names processing system are in hand, or within reach; however, what is still lacking is an overall systems design approach. This paper presents such an approach including design issues concerning: 1) a system configuration; 2) names and spatial databases; and 3) names processing operations (selection, positioning, and plotting).

HYPOTHETICAL SYSTEM CONFIGURATION

A typical names processing system consists of a minicomputer processor, disk drives, a tape drive, an interactive graphics work station, plotting capabilities, and a printer terminal (Figure 1). The processor must be able to manage characteristically large volumes of names/ spatial data and relatively complex names positioning software. The disk drives should have adequate capacity for storing the large names/spatial databases, font libraries, and operating system, utility, and names processing software. The tape drive is utilized for general communication, archiving, generating plot tapes for a plotting device, and so forth. The graphics work station consists of an interactive graphics display, keyboard, menu, digitizing table, and cursor. Finally, the system should be able to generate hardcopy products on several types of plotting devices and be able to produce lettering in several fonts.

In a typical session, the operator (map editor) <u>selects</u> names and spatial data from databanks. The system then automatically <u>positions</u> names relative to their respective spatial features, displays results, and prompts the operator for review and/or modification. The operator may then direct the system to generate a hardcopy <u>plot</u> of the spatial data and positioned names.

SPATIAL/NAMES DATABASE DESIGN

Two databases fundamental to a names processing system are a names database (NDB) and a spatial database(SDB). A NDB contains mostly descriptive or attribute data in reference to spatial features. A SDB, for the most part, contains spatial feature coordinate descriptions with some attribute data.

A names database or gazetteer (Figure 2) typically contains the feature name, spatial location, feature type (e.g. populated place), and feature attributes (e.g. population). Spatial location is represented in the database for a point feature simply by a spatial coordinate, for an areal feature perhaps by some arbitrary point inside the area, and for a linear feature by, for example, the mouth or source coordinate of a river.

Existing large scale names databases (e.g. the Geographic Names Information System at the U.S. Geological Survey and the Foreign Names Place File at the Defense Mapping Agency) are limited in scope in terms of automated names processing. Much of the information in these databases is duplicated in the associated spatial database, and it is often not possible to directly link feature names in the names database with their spatial features in the spatial database.

Spatial databases and structures have received considerable attention in the literature, (e.g. Peucker and Chrisman, 1975; Shapiro and Haralick, 1980). However, in the context of names processing, the integrated design of spatial and names databases has received relatively little attention.

An integrated design would allow for the identification of required information unique to both names and spatial databases and information that could be shared. By constructing direct linkages between the NDB and SDB, an integrated design would allow for the sharing of information, the construction of relations, and the avoidance of excessively redundant information. Linkages between the NDB and SDB may be implemented by several direct or indirect addressing schemes, for example, pointers, feature identification codes, and feature names.

An integrated design would provide an opportunity to consider tradeoffs between storing or processing information, and to consider strategies for capturing and building information. For example, one would want to store rather than repeatedly compute the area of a feature, and one would prefer to capture primitive geometric entities and from these build more complex relationships.

On the whole, an integrated design of names and spatial databases would optimize data capture, building, storage, maintenance, and processing operations. With an integrated design, the combination of information contained within a NDB and a SDB would represent an efficient store of information that as yet has not been available to the cartographic community.

NAMES PROCESSING OPERATIONS

Building on the description of a names processing system and the relevant databases, we now address names processing operations: 1) selection - the selective retrieval of names and spatial data; 2) positioning - the positioning of names amidst spatial data; and 3) plotting - the generation of softcopy and hardcopy names and/or spatial data products.

Selection

The selection operation consists of two sub-operations: spatial data selection and names selection. The map editor interactively specifies selection parameters (e.g. area, scale, resolution and theme) and then names and spatial data are automatically retrieved from the database. In spatial data selection the area will indicate the coverage, and the theme, scale, and resolution will determine the kind and detail of spatial information that will be retrieved (Figure 3). For example, the theme might effect the retrieval of a particular overlay, or certain spatial data within an overlay, and the scale and resolution will dictate the detail of spatial information and generalization. The retrieved spatial data will be stored in an application file where it can be efficiently accessed by the positioning and plotting operations.

The same set of spatial data selection parameters is utilized for names selection (Figure 4). Similarly, based on these parameters, a subset of information will be retrieved from the NDB and stored in an application file for the subsequent positioning and plotting operations. As the NDB application file is built, names will be classified according to theme, scale, feature type, and other criteria. For example, depending on the scale, a feature will be classified as a point or area feature type. In another example, if the theme is population of U.S. cities, each city will be classified according to some classification scheme (e.g. percentiles).

Other name parameters requiring specification in the application NDB are lettering characteristics such as font (style), size, and spacing. These parameters will be set automatically or interactively for each class of names as selected from the NDB. For example, all cities within a population range will be in one class and can be assigned a unique characteristic. Lettering characteristics, especially size and spacing, are required information for the positioning operation. Size, spacing, and font characteristics are required for the plotting operation.

During the selection operation the map editor may perform editing operations. He may examine and modify the names and spatial data, the classification of names, lettering characteristics, and selection parameters. The map editor will also be prompted for selected names and spatial data discrepancies. Discrepancy checking will be supported by the linkage structure which integrates the NDB and SDB. The linkage structure will assist in verifying the selection of names and associated features, and assist in monitoring feature type change, for example area feature change to point feature as a consequence of scale.

Positioning

Positioning consists of a control structure that integrates automatic multi-method positioning algorithms, spatial processing techniques, and map analysis and interactive capabilities (Figure 5). Methods for point, linear, and areal features will automatically position selected names amidst selected spatial data. The control structure, upon analyzing initial and iterative map conditions, utilizes decision criteria to determine the appropriate method or sequence of methods, or to transfer to interactive control where the final results are displayed on the graphics terminal. In this interactive environment the map editor is prompted for review and/or modification of the selected positions.

Point Feature Positioning. Figure 6 shows a scheme developed by Hirsch (1980, 1982) to position names around points. Overlaps between point feature names and other names or spatial data generate vectors indicating direction of movement toward open space. This information is translated into a particular movement strategy depending on the method of movement.

Area Feature Positioning. Figure 7 illustrates a method for positioning a name within an areal feature. First a minimum area encasing rectangle (Freeman and Shapiro, 1975) is derived. Then n line segments (n = to the number of name characters) are constructed equally spaced and orthogonal to the rectangle orientation. Mid-points between line segment and polygon boundary intersections mark the positions for each character.

The orientation of each character may be orthogonal to the horizontal x axis, the rectangle orientation, or to a trend line fitted to the mid-point positions. This method produces a name placement solution that is representative of the area's shape and extent.

Linear Features Positioning. Figure 8 displays a scheme for positioning a linear feature name along a river. The name may slide from left to right, above or below the river depending on the information content of an overlap vector (i.e. an indication of symbol density in the local area).

Interactive Adjustment. When decision criteria indicate that position processing is completed, the control structure directs control to the operator. At this time the spatial and names data may be displayed on the graphics terminal for review and/or modification. The results may be saved on disk or directed to a plotting device.

Plotting

The plotting operation consists of the capability to generate softcopy and hardcopy products on a host of standard display and plotting devices. Pens, scribing tools, photoheads, CRT photoheads, electron beam recorders, laser, and electrostatic matrix plotters are examples of standard plotting devices. Speed and accuracy tradeoffs between these different devices must be considered. Softcopy products on display devices are desired for quick review and analysis or to be copied by screen scanning copiers.

Input required by the plotting operation is accessed from the application names and spatial data files. This input includes a full specification of names to be plotted (text, starting location, orientation, and lettering characteristics). A comprehensive selection of lettering styles or fonts should be available from a font library. Examples of products are final names overlays, spatial data overlays and combinations.

CONCLUSION

All of the major components of a names processing system (the proposed system configuration, names and spatial databases, and names processing operations) are now approachable given available technologies. An overall systems design approach is necessary for the design and development of an intelligent system. Names and spatial databases require an integrated design in order to optimize data capture, building, storage, maintenance, and processing operations. The automation of names processing operations requires the support of a map editor in an interactive processing environment. Finally, further research is required for the positioning operation, in particular for the development of a decision-based control structure.

FOOTNOTE

1) The Oxford System (Bickmore and Boyle, 1964); The Automatic Type Placement System (ATPS) developed by the U.S. Army Engineer Topographic Laboratories for the Defense Mapping Agency; and cartographic name processing system efforts at the University of Saskatchewan, Canada (Boyle, 1973 and 1974; Wilkie, 1973).

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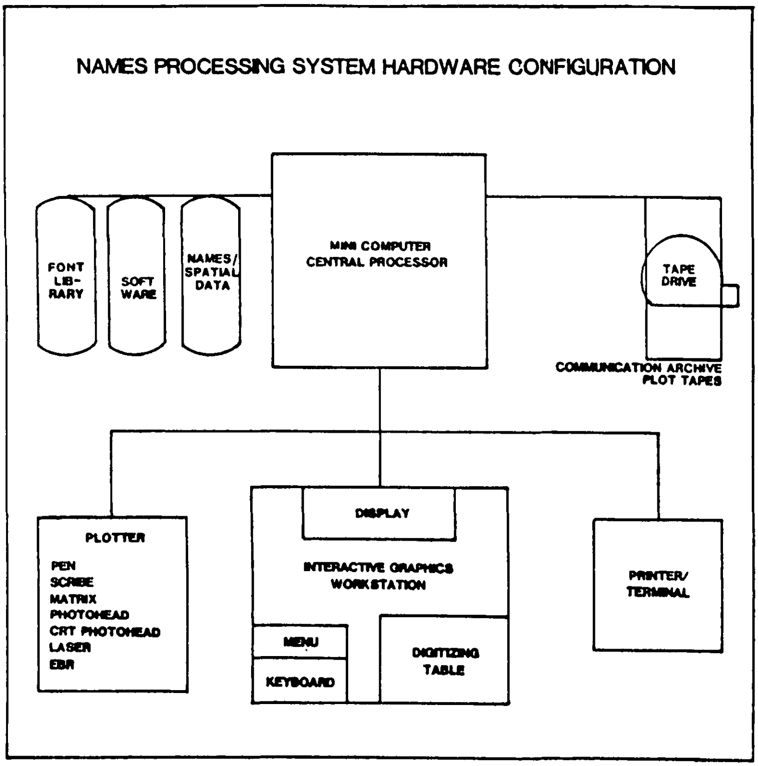

Figure 1. Components of a typical names processing system.

NAMES DATABASE

NAME	LOC.	FEATURE TYPE	SUBTYPE	ATTRIBUTE
HUDSON RIVER	X,Y	LINEAR	RIVER/BROOK	LENGTH/LOAD
BOSTON	X,Y	AREA	STATE CITY/CAPITAL	AREA/POPULATION

Figure 2. Standard information contained in a names database.

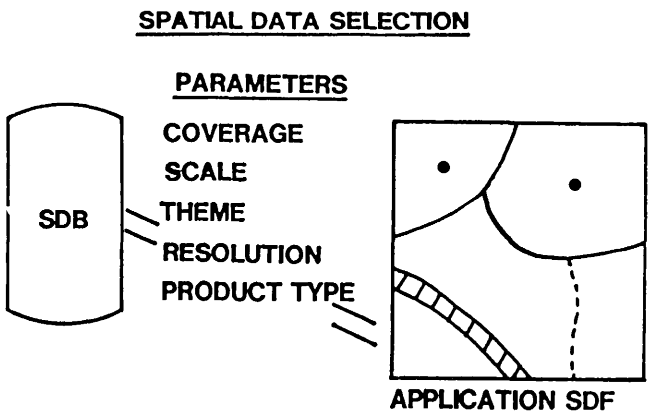

Figure 3. Based on selection parameters, spatial data are retrieved from a spatial database and stored in an application spatial data file (SDF).

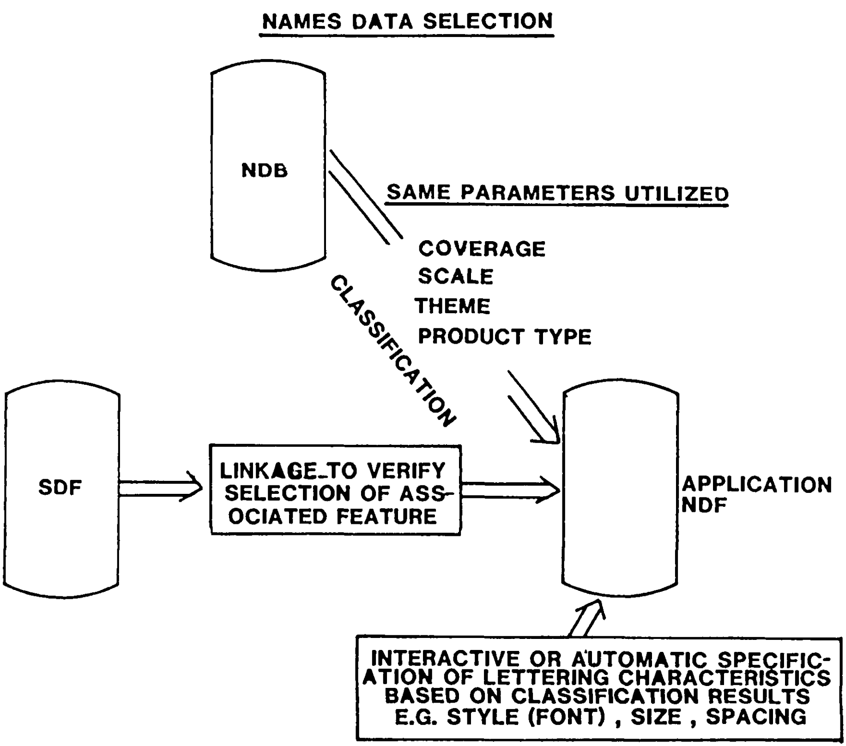

Figure 4. Based on the same selection parameters, names data are retrieved from a names database (NDB).

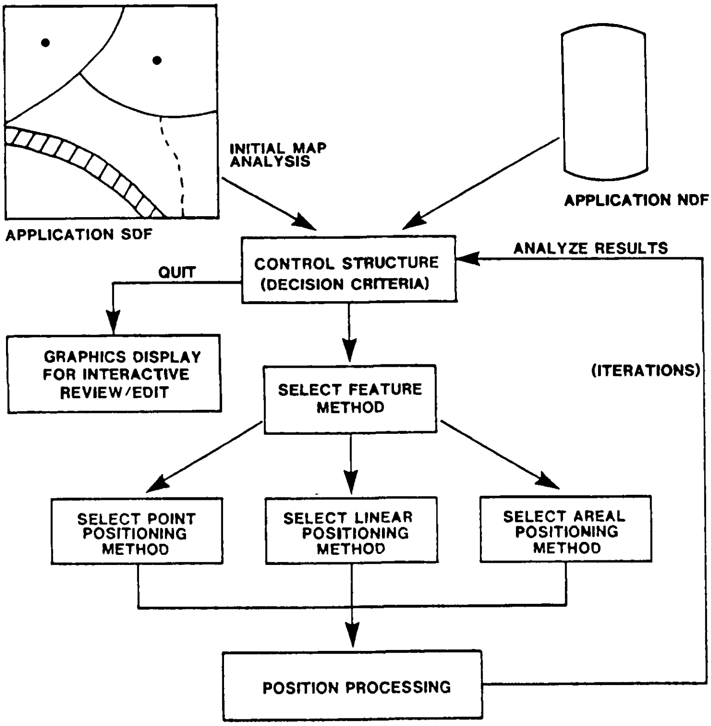

Figure 5. In the names positioning operation, a control structure integrates automatic multi-method positioning algorithms, spatial processing techniques, and map analysis and interactive capabilities.

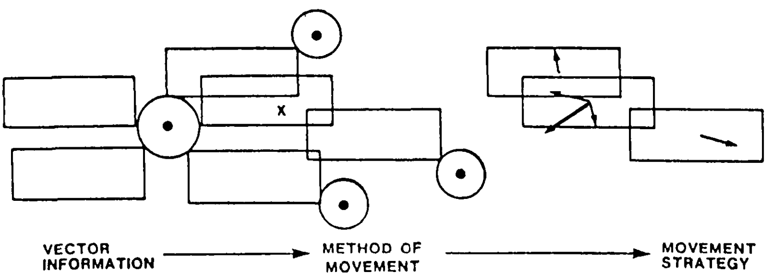

Figure 6. An example of point feature positioning utilizing overlap vectors.

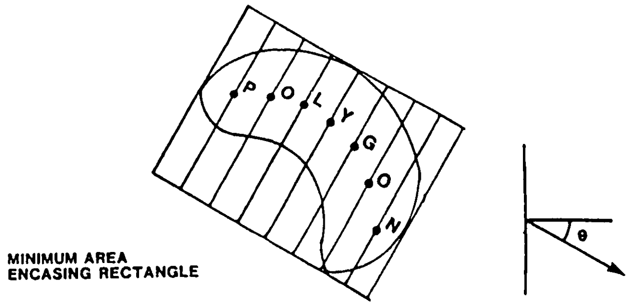

Figure 7. An example of area feature positioning.

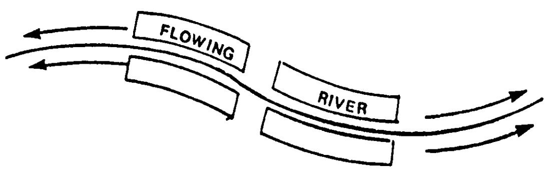

Figure 8. An example of linear feature positioning.

ADVANCED VERY HIGH RESOLUTION RADIOMETER (AVHRR) DATA EVALUATION FOR USE IN MONITORING VEGETATION, VOLUME I - CHANNELS 1 AND 2

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ABSTRACT

Data from the National Oceanic and Atmospheric Administration satellite system (NOAA-6 satellite) have been analyzed to study their nonmeteorological uses. The useful limits of these data were also determined. A file of charts, graphs, and tables was created from the products generated in this study. It was found that the most useful data lie between pixel numbers 400 and 2000 on a given scan line. The analysis of the generated products indicates that the Gray-McCrary Index can discern vegetation and associated daily and season changes. The solar zenith-angle correction used in previous studies was found to be a useful adjustment to the index. The Metsat system seems best suited for providing large-area analyses of surface features on a daily basis.

INTRODUCTION

The advanced very high resolution radiometer (AVHRR) system aboard the NOAA-6 satellite can simultaneously observe reflective energy in selected bandwidths of the visible and near-infrared parts of the solar spectrum (similarly to the Landsat MSS system) and can provide data relevant to agriculture. These new uses of the Metsat would complement the higher resolution Landsat data and provide more timely coverage.

Currently, the Foreign Crop Condition Assessment Division (FCCAD) of the U.S. Department of Agriculture, Foreign Agriculture Service (USDA/FAS) processes an index similar to the GMI in real time; however, the restraints and limits applicable to such indexes are unknown. The primary purpose of this study is to define these limits of acceptability for Metsat data.

POLAR ORBITING ENVIRONMENTAL SATELLITE CHARACTERISTICS

The data used in this study were collected by the NOAA-6 satellite and recorded at Wallops Island, Virginia, from real-time transmission. These data are identical in content to the Local Area Coverage (LAC) data. The major differences between the Landsat MSS and the NOAA AVHRR systems are an image resolution at nadir, image width, and temporal continuity.

The AVHRR spectral bandwidths of the reflective channels, 1 and 2, were chosen to aid in the detection of snowmelt, an environmental phenomenon relative to hydrological forecasting. Channel 1 responds to reflected energy in the yellow-red portion (550-700 nm) of the visible spectrum and thus has a minimum response to verdant greens. However, the channel 2 bandwidth responds to the reflected energy in the near-infrared part of the spectrum (700-1100 nm) and acquires high values from vegetation.

THE GRAY-MCCRARY INDEX

The GMI is defined as the difference in the returns from channels 2 and 1. This index, which emphasizes the variations of healthy vegetation and provides negative responses for clouds and water, is relatively simple and can easily be placed into current operational activities.

Both clouds and water generate higher returns in channel 1 than in channel 2, consequently producing negative GMI values. For both channels, the cloud returns are high and the water returns are low, thus permitting the implementation of an analytical tool, "ramps." These ramps substitute one value for a variable negative result based upon the characteristics of channel 1.

We chose to set all cloud values (channel 1 response of 9% or greater) to a ramp of -1.5; all water, snow, and ice values to a ramp of -0.5; and certain indeterminate targets to -1.0. This approach reduces the emphasis of these targets and accentuates the remaining positive quantities for vegetation.

The GMI value was calculated for each pixel over the study area. A solar zenith angle correction was applied to the GMI values to simulate a condition of the same sun angle, regardless of the actual sun angle. The equation for the corrected GMI value is:

$$GMI^* = GMI(\sec^2 z)(\cos 39^\circ)(10)$$

where GMI* is the corrected GMI values and z is the solar zenith angle for the given pixel location. The value of 39° was chosen to adjust the data to the nominal solar zenith angle of Landsat scenes. The entire quantity was multiplied by 10 to facilitate data handling.

Generally, the values of the GMI vary from -1.5 to 32.0. Healthy vegetation produces values that range from about 8.0 upward. Soils have responses that vary from slightly less than zero to about 4.0 (ref. 5).

The most accurate values of the GMI occur for pure-pixel views. A mixed pixel will contain inputs from many different sources, and thus the GMI value for that pixel will be altered. Pixels over pure vegetation give the highest return. A comparison of two pixels, one pure and one mixed, shows that the resultant GMI for the mixed pixel is less than that for the pure pixel.

THE TARGET AREA

Charts showing the 1979 distribution of major crops in Illinois are given in figure 1 (ref. 7). While these charts are not for 1980, previous charts reveal that the specific growing regions have changed very little.

A grid system shown in fig. 2, was placed over a map of this region to subdivide the acquisition into smaller sections and provide a basis for analysis. The i,j-grid system is a superset of the grid devised by Charney in 1952 (ref. 8) for computer analyses of meteorological data. This superset has the same orientation of that grid system where the i lines are parallel to 80° W. and the j lines to 170° W.

ANALYSIS AND INTERPRETATION OF RESULTS

In a study of this type, all available relevant data should be examined. The use of multiple methods of analysis is far more advantageous than dependence upon one particular system or procedure.

Scatterplots

A total of 33 scatterplots, plotting channel 2 versus channel 1, was produced to determine the AVHRR responses to various surface conditions. This effort includes a look at temporal changes in the GMI values and the results are presented in Table 1. The July ranges are all greater than those of October. In July, the natural vegetation and crops (corn and soybeans) appear green and thus have GMI values in the 6 to 10 range. The October ranges (2 to 3) seem to depict harvested fields (bare soil) and the autumn coloring of the forest. The areas surveyed in October might include bare trees, thus making the ground visible to the sensor.

The wide range of GMI values for the St. Louis area seems to indicate that the city includes large areas of trees and parkland. Thes tree-covered areas would explain the resemblance of some city plots to those of forest and cropland and would account for the change in GMI range for data gathered in autumn.

Nine of the scatterplots show some degree of cloud contamination. Most of these plots are from July periods, when there was some frontal activity in Illinois. While it is easy to guage the effect of large cloud fields, it is difficult to assess the contamination due to subresolution

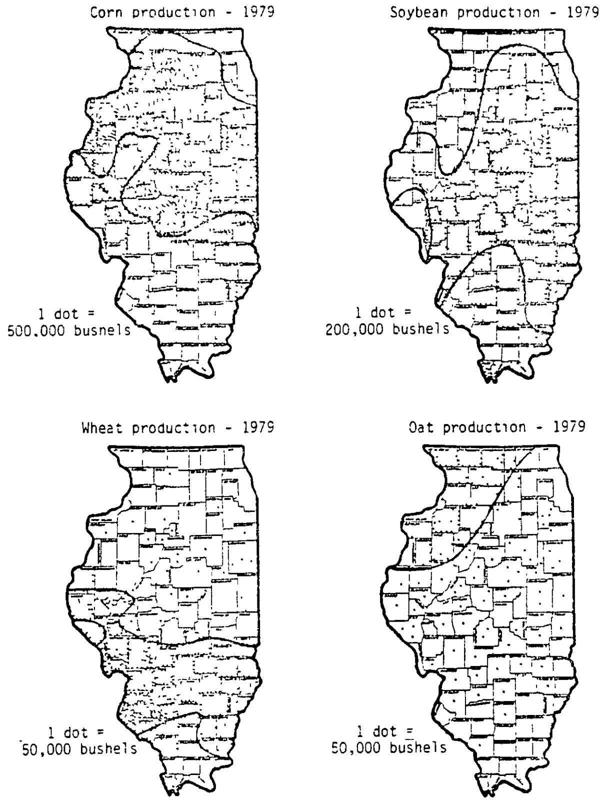


Figure 1. - Distribution of Major Crops (Ref. 7).

cloudiness. These clouds will contaminate otherwise high-value pixels, producing mixed pixels with lower returns, altering the surface appearance.

GMI* Data Analysis

The charts of the GMI* values were produced to examine spatial and temporal changes in the index over the target area. One chart was made for each day in both the July and October periods.

A persistent minimum feature was found in the data collected for St. Louis during the July period. This seems to be reasonable, because a city consists of concrete, asphalt, and other surfaces that offer lower returns than does vegetation.

Temporal changes in the GMI* were observed after rainfall. During the 24-hour peirod after the rain fell on July 10, the GMI* values were low for the specific area covered by precipitation (northwest section of the target area). In the following 24 hours an increase in the GMI* values was

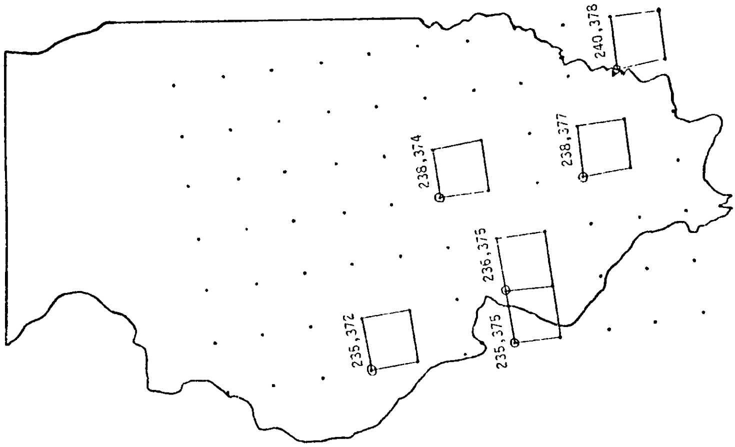


Figure 2. - Grid Cells (i,j) Used for Scatterplots.

observed for the same area. This change can be explained by considering surface conditions during this time period: For the 24-hour period immediately after the rain fell, the ground and plants probably were still wet, thus producing low-return signatures and subsequent low GMI* values. Then, in the next 24 hours, when surface conditions had become drier, the plants appeared greener, either having benefitted from the additional moisture, or having become cleaner because the rain washed any dust and dirt off the plants.

Solar Zenith-Angle and Pixel Considerations

It has been found that views with low pixel numbers (below 400) tend to have excessively high GMI* values. This is due to the solar zenith-angle correction, sec z, which increases rapidly above 70°. Illumination of the target does not change above 70° according to the sec z correction.

Transection Analyses

Transections were made of both the corrected and uncor rected GMI values. While they have almost identical characteristics, the corrected GMI curve has a sharper slope than does the uncorrected GMI curve. The west-to-east slope of these curves (low pixel numbers to the west) might be explained by land forms and vegetative cover. Another factor to consider is the solar elevation angle when these data were collected. At 0700 the eastern half of the scan will be sensing forward-scattered radiation, and the western half of the scan will be sensing backscattered radiation.

TABLE 3-1.- RANGES OF GMI VALUES FOR GIVEN GRID SQUARES

Day	GMI value range					
	Good cropland and Illinois River i,j=235,372	Good cropland i,j=238,374	City of St. Louis i,j=236,375	Forest and Rend Lake i,j=238,377	Ohio and Wabash Rivers and forest i,j=240,378	City of St. Louis i,j=235,375
191	†5 to 7	†7 to 8				
192	†6 to 8	All cloud				
193	†8 to 10	7 to 9				
194	9	8 to 9				
195	†-3 to 7	†6 to 7				
195	†1 to 3, 7 to 9	†6 to 9			All cloud	
196	8 to 10	7 to 8				
197	8 to 10	8 to 9	8 to 9	7 to 9	8 to 9	5 to 9
280	2 to 3	2 to 3				
282	2 to 4	2 to 3				
283	2 to 3	2 to 3		2 to 3	2 to 3	
284	1 to 2	†0 to 2	2			

†Includes contamination by clouds.

Table 1. - RANGES OF GMI VALUES FOR GIVEN GRID SQUARES

Additionally, transections were made of the actual raw-pixel values from channels 1 and 2. All of these raw-pixel-value curves slope upward at the ends, while the central portions are rather flat. The end effects are the result of the Sun-Earth-satellite geometry. Thus, while pixel size does increase away from nadir, the predominant end effects are due to preferential scattering of the incident radiation. Because of this systematic end distortion, the flat, central part of each curve probably offers the most reliable data.

Resolution Deterioration Considerations

Graphs were drawn to display pixel deterioration away from nadir and to determine the usable portion of the scan line. Figure 3 shows that the largest range of values appears on the low-pixel-number end of the scan line. The collection of data begins in the west, or away from the Sun, and the data are collected toward the Sun. Because of the early morning acquisition time, the western end of the scan line is contaminated by shadows and the eastern part of the scan line is contaminated by sun glint. Also included here is a portion of the scan line covered by the Illinois target area. The location of the Illinois area on the scan line will determine the number of pixels included in said area. This difference is attributed to the way in which pixels change in size away from nadir, as shown in figure 4. At the edge of a scan line, the pixels are longer, thus covering more area individually.

These two graphs, in conjunction with the daily GMI* charts, were used to determine what parts of the scan line should be eliminated. If the central 1200 pixels are used and the outer portions are discarded (400 pixels on either end), the data remaining will be of good quality, thus eliminating extreme GMI* values and minimizing errors which are due to pixel size.

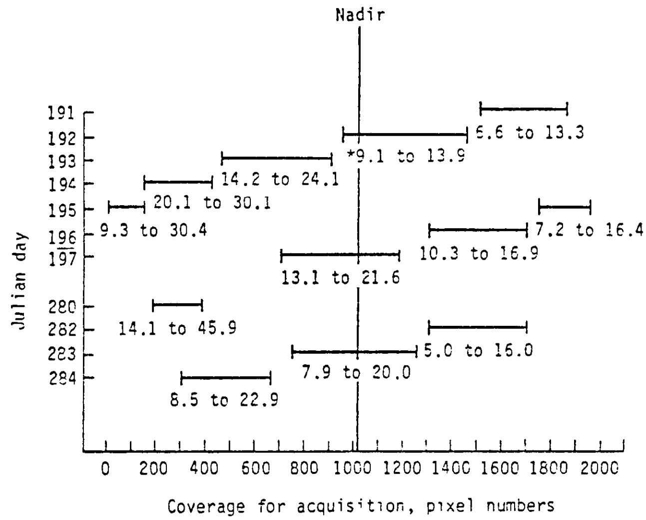
Data and Index Corrections

Calculations of the GMI values were performed both with and without a secant solar zenith-angle correction. In all cases the shapes of contours and patterns of lines were very similar. Even so, the correction will give all the data the same sun angle and make the comparisons, especially the monthly ones, much more valid.

The problem of atmospheric scattering and absorption was not considered in this study.

Charts of Weekly GMI* Maximums

Probably the best way to utilize this index is through the use of the analyzed fields of weekly GMI* maximums. GMI* maximums were selected to minimize atmospheric attenuation because high values of this index will coincide with relatively clear days. Figure 5 shows the GMI* maximums for the July and October acquisitions. In these particular charts, data from days which appeared on the low-pixel-number end of the scan were eliminated.



*Range of GMI values for acquisition.

Figure 3. - Width and relation to nadir of each acquisition on a scan line

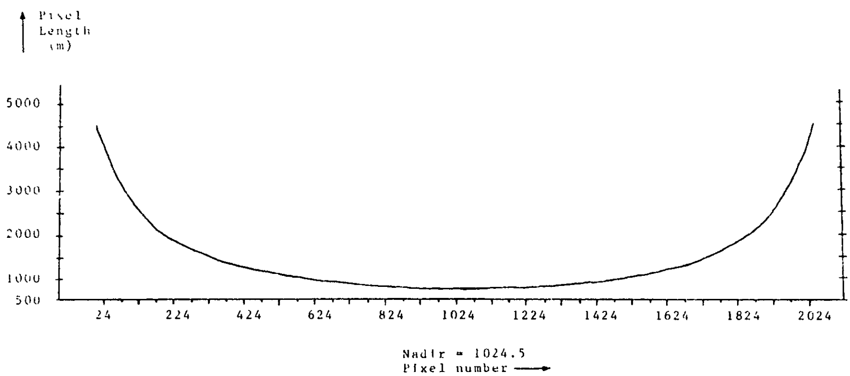


Figure 4. Plot of pixel length away from nadir (ref. 12).

The resulting patterns on these GMI value charts were then compared with the chart of the distribution of major crops (fig. 1) and with the agricultural analysis.

In July the central maximum area on the chart of GMI* values corresponds with the areas normally planted in corn and soybeans. The southern minimum areas correspond to the wheat-growing regions. The axis of the minimum area in the northwestern part of Illinois lies along the valley of the Illinois River, and a minimum value also appears for an area centered in St. Louis.

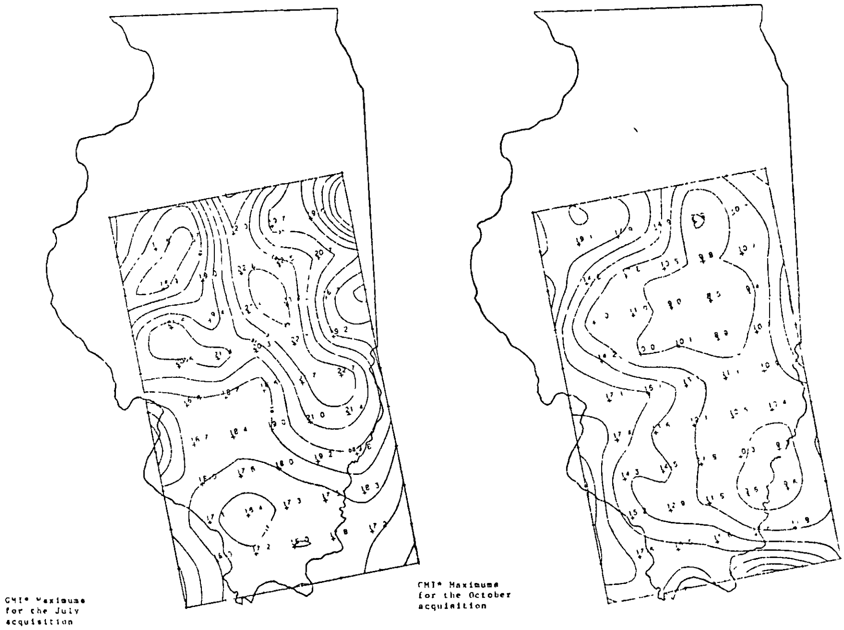


Figure 5. - Maximum GMI values

When the agricultural data analysis was examined, both the corn and soybeans were found to be reasonably healthy (high GMI* values); the wheat was almost completely harvested (low GMI* values); and the oats were turning yellow (low GMI* values).

For October, the central minimum area corresponds with the corn and soybean area, which at this time was more than 50 percent harvested (low GMI* values). The wheat areas were undergoing planting or plowing and consequently had a similar response (low GMI* values) to that for July. Since wheat is grown on a small scale in Illinois the low GMI* values over the wheat growing region might not reflect the health of that specific crop. However, this area did have some of the highest temperatures and the least amount of rainfall during the July and October acquisitions. Consequently, the low GMI* values there could indicate the amount of stress on all the vegetation.

These comparisons indicate that cultivated vegetation can be observed with the NOAA AVHRR. While the GMI produces broad-area estimtes and can make only a gross estimate of vegetative conditions, it oculd be a useful tool and adjunct to current operational systems.

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AN EVALUATION OF A MICROPROCESSOR BASED REMOTE IMAGE PROCESSING SYSTEM FOR ANALYSIS AND DISPLAY OF CARTOGRAPHIC DATA

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ABSTRACT

The Earth Resources Observation Systems (EROS) Data Center has developed a prototype Remote Image Processing System (RIPS) which utilizes off-the-shelf microprocessor technology and a color raster refresh display. Although it was designed primarily for low cost interactive image analysis, the system is being evaluated for use in cartographic analysis and display tasks.

Similarities and differences between RIPS-type raster refresh display systems, and minicomputer-driven graphics terminals which are commonly used to display cartographic data were investigated. It was determined that many traditional differences have been eliminated because (a) new cartographic analysis systems are often configured with raster refresh displays, and (b) image analysis systems have been programmed to accept and display cartographic data.

In order to evaluate the applicability of RIPS for cartographic analysis tasks, representative spatial analysis algorithms were performed on RIPS and compared to a minicomputer with a graphics display. Tests included routines for point-in-polygon matching, line drawing or rasterization, spatial filtering, and image classification. Results indicate that many functions that have traditionally been relegated to larger machines can now be efficiently performed by microprocessor systems.

Based on the results of these tests, optional RIPS configurations were defined for increasing spatial resolution (at the expense of spectral resolution), and for substituting faster winchester type disk drives for lower cost floppy disks. Future versions of RIPS may also incorporate a coordinate digitizer and an electrostatic plotter.

INTRODUCTION

The EROS Data Center has developed a prototype microprocessor system for conducting interactive image analysis tasks using a color raster refresh display. Over the last two years, system software and applications demonstration programs have been written and tested on the microprocessor.

Based on this experience, it was determined that the system was capable of performing selected spatial analysis tasks which utilize cartographic data as input or which result in cartographic output. It was decided to test the system by performing various cartographic analysis and display tasks, and to compare its performance with other systems which are in operational use at the EROS Data Center.

THE RIPS PROJECT

Since 1974, EROS's Data Analysis Laboratory has been used extensively for training and cooperative demonstration project work. Although many users have conducted successful pilot projects, some were unable to make operational use of digital techniques because (a) image processing systems typically cost over $500,000, and (b) interactive processing requires a resource analyst with field experience as well as digital processing skills. High costs dictated a centralized facility, but the need for extensive user/system interaction made it necessary to locate the system near the project study area.

A microprocessor system was envisioned which would be able to display a "full color" raster image with resolution suitable for detailed analysis. It would also allow the user to perform interactive tasks on-site, via an image display and a terminal (Waltz and Wagner, 1981).

The prototype system was based on a Z80 microprocessor (a common 8-bit CPU), an S100 Bus (for ease of interface to peripherals), a 256 x 240 x 12-bit color display (4 bits each of red, green, and blue, or 8 bits of black and white), and an RS232C type terminal. A list of these "off-the-shelf" components is available (Wagner, 1981).

Design goals stressed simplicity and low cost, and included the following:

(a) The system was to communicate with a host computer system (including image transfers) at 1200 baud using a standard telephone line (Wagner, 1981).

(b) The system was to be programmable on-site, and would have sufficient file handling and display utility routines to allow applications programs to be easily written.

(c) The system would be capable of displaying continuous color (4096 colors) to support display of raw and enhanced digital multispectral scanner imagery such as digital Landsat data.

When the first system was built, it became clear that any microprocessor capable of creating a minimal (but adequate) display was also capable of much more. Programs which could be run on the RIPS also had the advantage of a dedicated processor, and avoided the telephone line bottleneck (Note: If supported by a host computer, RIPS itself is not limited to 1200 baud. The purpose of this limitation was to utilize readily available telephone lines and equipment and to place importance on data compression and efficient image handling protocol.)

EROS has built three RIPS stations to date, and has a procurement pending for six to twelve more (the additional six are options which may be exercised by EROS or by other Department of Interior agencies). In addition to supporting project work, the RIPS will also be used in a digital classroom planned for EROS's training courses. The RIPS stations will be relatively portable with the ability to be packed as three separate units for transport (Figure 1). The pending procurement is based on a functional

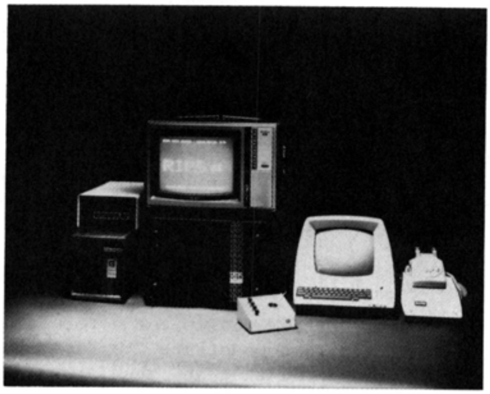

Figure 1. The RIPS System

specification, and is being competitively bid in the hope that private sector involvement will be stimulated to create further efficiencies through repackaging, optimization, and extension of the basic design.

One of the most significant contributions of the RIPS design project has been the development of a simple but elegant protocol for handling image data over standard telephone lines (Nady, 1981). Also, a prototype applications software system, for typical image processing functions which are used for analysis of remotely sensed data, has been developed to demonstrate and test the RIPS (Holm, 1981).

Comparison of RIPS With Traditional Cartographic Display Devices

Several technological advances have occurred in recent years which have improved raster refresh displays and lowered costs dramatically. For example, RAM memories are commonly employed in newer cartographic displays to allow for fast access, selective erase, and hardware zoom and roam features.

Most cartographic display terminals are configured with relatively high resolution (512^2 or 1024^2), corresponding to the address space available in the older technology storage tubes. As most color CRT's are not capable of resolving more than about 600 discrete samples per scan, a special, expensive CRT is needed to properly appreciate 1024^2 resolution.

RIPS, on the other hand, is presently limited to a 256 x 256 display with the spatial restriction stemming not so much from the cost of additional RAM, but rather from the time penalty incurred when transferring a 512^2 image over a standard telephone line. For example, a 512^2 image takes four times longer to transfer, and provides only a marginal improvement in the visual display. Image compression techniques can improve on the transfer time, but do not eliminate this problem.

The RIPS has an extended 12-bit spectral resolution (4096 colors) compared to from one to four bits resolution (up to 16 colors) in typical cartographic displays. This difference is important, and should be considered in selecting the best system for a given set of applications. For example, a high resolution monochomatic display is best for displaying intricate line work, while RIPS might be preferred for displaying line work superimposed on a continuous raster image such as topography, aeromagnetics, or a multispectral scanner image (for example, Landsat MSS or TM).

1) Display of Vector Data

RIPS was designed as a display device for a regular grid of data, so a program was written to demonstrate its capability to convert cartographic line work to a raster and then display it. The test consisted of displaying the line work superimposed on a false color composite background image (Figure 2). The lines were

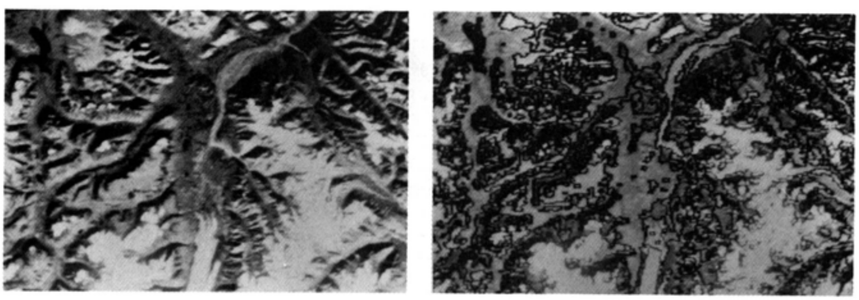

Figure 2. Landsat MSS display (left). Line drawing (right) superimposed on display.

extracted from a Landsat image using an unsupervised spatial/spectral clustering algorithm (Jenson and Bryant, 1981) and converted to topologically structured edges (Nichols, 1981). RIPS was then used to (a) read the coordinate pairs from disk, (b) convert the coordinates to screen relative locations, and (c) rasterize (draw a line) between each point pair. The minicomputer system utilized a standard terminal control system (TCS) to draw vectors on a storage CRT (Figure 2).

Surprisingly, RIPS was able to rasterize and display the lines over seven times faster than the minicomputer could draw them on a storage CRT, because the minicomputer output was limited by a 2400 baud terminal port (which is a typical limitation on a general purpose machine and was the fastest terminal port supported by the system).

2) Spatial Filtering

Spatial filtering was tested to demonstrate the potential for processing local spatial operators (for example, topographic slopes from terrain elevation, spatial diversity or texture from Landsat data, or first and second derivatives from gridded geophysical data). A general purpose convolution filter algorithm is currently implemented which was determined to be the functional equivalent to these more specialized examples.

The convolution test is a test of the computational horsepower of the RIPS, as it requires nine multiplies, nine adds, and one divide for each of the 61,440 pixels.

In this case, the RIPS shows itself to be adequate for a 3 x 3 neighborhood operation on relatively small areas. The run time for this program was 110 seconds, which is tolerable for most interactive analysis tasks. In comparison, an IDIMS (HP3000) system processed the same area in 72 seconds. For larger areas however, (larger than 256 x 240 pixels), a larger system would be clearly advantageous. With a special purpose array processor, the IDIMS execution time was reduced to 11 seconds. The need for such a processor may be justified for very large images (for example, an MSS scene of 3548 x 2983 pixels, or an RBV image of 5322^2 pixels), or when fast iteration or execution turnaround is needed as in real time parameter adjustment. The output from RIPS (Figure 3) is functionally identical to the IDIMS output.

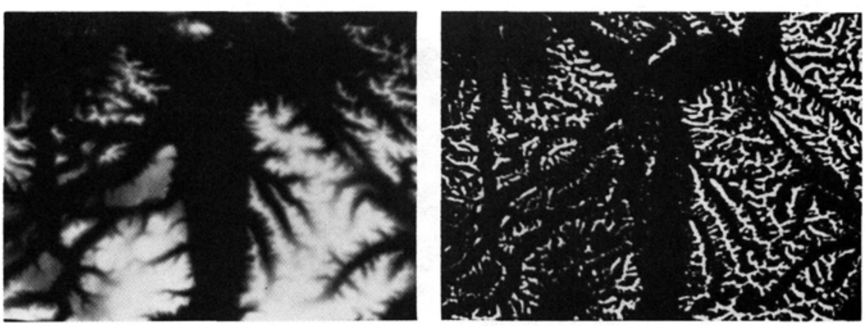

Figure 3. Digital Elevation Model display (left). Convolution filter (Laplacian) applied to elevation (right).

3) Point in Polygon

In addition to display of vector data, certain calculations are performed regularly on point, line, and polygon data. The point-in-polygon algorithm is such a function, and is used in connection with polygon overlay operations and other tests for containment. While the RIPS might not be appropriate for a generalized polygon overlay, it is concievable that other containment tests will be needed. For example, a point-in-polygon test can be used to validate the mathematical centroid as an interior point for purposes of labeling plotted polygons.

This is a simple test of the CPU's ability to perform integer arithmetic and logical tests. RIPS is slower than its minicomputer counterpart, but adequate for all but large data base overlay tasks.

4) Image Classification

Image classification is not generally considered to be a cartographic analysis task, but is discussed in this paper because (a) classification is the means for converting radiometric values to information classes which can be used to generate choropleth maps, and (b) the classifier which is employed on RIPS is optimized for a microprocessor and illustrates some fundamental differences in approach. In this test, the minicomputer uses a maximum likelihood classifier algorithm which requires calculation of a quadratic equation for all possible classes of each pixel. For a large study area, or a large number of potential classes, this calculation is potentially quite slow. Classification is one of the more challenging of image processing problems, and can require the use of a bigger (and faster) machine or parallel computing. Alternatively, a simpler decision rule can be employed.

On RIPS, a classifier was implemented based on a minimum (transformed) distance to the means decision rule (Holm, 1981). The execution time of 598 seconds was comparable to the maximum likelihood classifier on a much larger and faster CPU (528 seconds). The RIPS was able to classify an image (Figure 4) in a

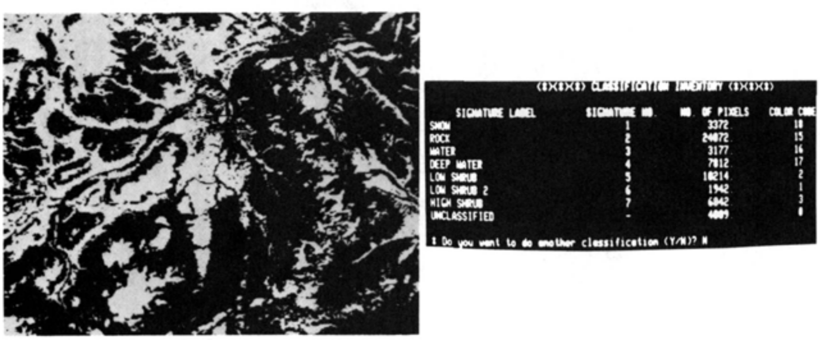

Figure 4. Multispectral classification result (Suits classifier).

reasonable time because the Holm implementation of the Suits decision rule can be performed using integer arithmetic and is optimized for the RIPS.

Results have not been checked for accuracy, but a qualitative comparison indicates that this classifier has promise and that further applications testing is appropriate.

5) Zone Search

Some applications require that distance to points, lines, or areas be calculated. In image processing, this function can be computationally expensive, since distances would be calculated between every pixel and all the feature(s) being tested. A large computer (B6700) implementation of this algorithm has been used at EROS for this purpose. In one project, a minimum distance search was run on a (raster) road network to determine pixels within a half kilometer (approximately 17 cell) radius of a road (Miller, W. and others, 1981). A total of over 52 hours of computer time was required for a 1800 x 2200 study area!

On RIPS, several simplifying changes were made. First, rather than calculate distances for each cell, the features (points, lines, areas) are preserved as entities in the image and the searching becomes a function of the number of features rather than all the pixels with features present (Miller, S., 1981). Also, the output is changed to a binary value (in/out) rather than a calculated distance, and utilized the random access memory of the RIPS display. A 10 cell radius zone search which executed in 141 seconds is shown in Figure 5.

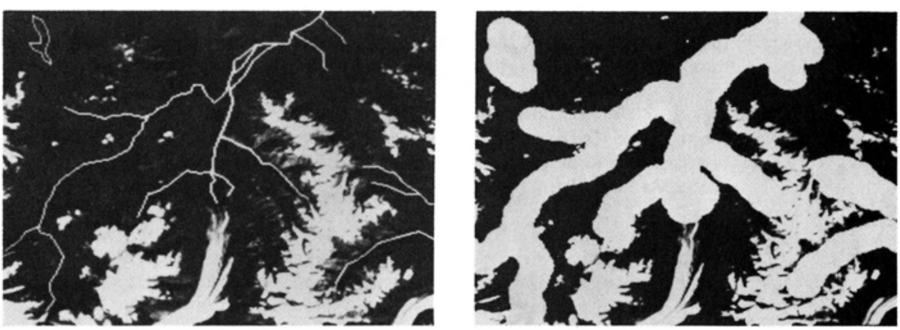

Figure 5. Surficial Hydrology network superimposed on Landsat MSS (left). Result of zone search (right) showing areas within 2.5 km radius of water.

SUMMARY AND CONCLUSIONS

Several tests run on the RIPS have shown that it is capable of performing spatial analysis tasks and displaying cartographic data. On the basis of these tests and others which have been performed as proofs-of-concept, development in several areas is anticipated. EROS and other RIPS cooperators will be developing applications software and extending the hardware to include a) a coordinate digitizer input capability, b) a vidicon scanner input, and c) a major software upgrade with extended image size and format handling, program-to-program communication, and vector handling primatives.

Also, under consideration are the addition of a 16-bit microprocessor, winchester disks (which are faster and have a larger storage capacity), and configuration of a 512^2 display for selected applications.

RIPS has been linked to two host computers to date, and it will likely be linked to two more machines in the near future. As software is written to utilize this lower cost technology, it is anticipated that many RIPS and RIPS-like systems will be custom tailored for image processing, cartographic entry and output, spatial analysis, and teaching applications.

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AN INVENTORY OF FRENCH LITTORAL

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ABSTRACT

The production of inventory mapping requires the collection of a considerable amount of data. Dizitizing those data and using powerful computer procedures opens new perspectives for using thematic cartography.

The Institut Géographique National-France, has developped a cartographic processing chain whose major assets are the constitution of files and the use of an automatic plotter. That chain was constructed, in particular, for producing an inventory of the littoral showing both land use and land legal status. Hand-drawn documents are produced in the normal manner either by interpreting aerial photographs (land use) or based on data collected from local authorities (legal status).

The outlines of zones and administrative boundaries are digitized by scanning equipment and coding is carried out in an interactive manner.

The area symbols and screens are generated by automatic plotting in order to produce the films required for offset printing. Thematic files are crossed with administrative files in order to produce statistical data banks.

New products can be produced from such digital data, for example,

(a) Synthesis derived maps
(b) Maps produced crossing several themes,
(c) Statistical calculations.

As the programme will be repeated every five years it will be possible to up-date the files and automatically compile evolution maps.

INTRODUCTION

Along the 5 000 km of the French littoral one encounters zones devoted to agricultural, tourist or industrial activities : wild rocky coasts, meadows, forests, long sandy beaches, marshy deltas and ports. This littoral is the object of important economic projects proposed by major companies and pressure groups.

The mapping of the littoral is destined to make that sensitive zone better known, to guide public authority policy and to facilitate negotiations between different groups.

In order that the inventory should not only be an historical record but, in addition, a real tool for regional development it was given a dynamic aspect by taking land use evolution into account and by displaying the differences between the theoretical use of that space as planned by legislation and the actual use that one observes on aerial photography.

The benefit that one expects from automatic cartography clearly appears here : by including the building-up of computer files in the map compilation procedure, the data are gathered in a form which ensures their perfect conservation and makes it possible to use them in the best conditions. The techniques used must be sufficiently effective for processing this type of mapping, both as regards graphic quality as well as costs and delivery times.

THE DATA

Limited to a coastal strip about 5 km wide, the inventory mapping has two major aspects :
(a) land use as currently observable (147 large format sheets at 1:25 000),
(b) legal status of the land (23 sheets at 1:100 000) destined to orient the present and future use of the space.

Land use

The use of the land sector is obtained by medium-scale photo-interpretation carried out by the Institut Geographique National (I.G.N.-F). The main divisions of the resulting map legend differentiate between the urban, agricultural, natural and coastline spaces. Information on the maritime sector is collected from local authorities and concerns marine breeding and natural resources zones which are being exploited or have to be protected.

Legal status

The legal status of the land is also established using data supplied by local authorities. It has two components :

(a) Legal status of the ground as obtained from town planning documents, forestry regulations, national parks, nature reserves, wild sites, historic monuments and maritime law.

(b) Ownership of public authorities.

CARTOGRAPHIC COMPILATION

Digitization

Data digitization is carried out in two stages. The outline overlays obtained by scribing are oriented in accordance with the Lambert system, and analyzed automatically by a scanner. The grid file so obtained is processed in order to skeletonize the outlines and correct imperfections, then to attribute a common code to all the points of the same unit. One thus obtains a computer file which is termed "geographic".

One then proceeds to the coding of the thematic information ; one establishes a correspondence between each unit and the thematic code supplied by the overlay, then transcribes the result on to the computer support, obtaining the "statistical" file. That coding is carried out interactively, by means of a digitizing table, by levelling inside each land parcel : double coding makes it possible to eliminate errors.

The entire group of information forms the littoral data bank.

Legend

The development of the legend, in its graphical representation, was carried out taking two constraints into account :

(a) Automation of the largest number of production stages so as to reduce the manual interventions, and so the prices and delivery times,

(b) Production of very high quality mapping whilst using only four coulours, again for economic reasons.

The area symbols were drawn using an interactive colour display and building up a library : the typography common to all the maps in the series (titles and subtitles) was digitized using a scanner in order to complete a file carrying the legend.

Offset film output

The output of offset film from the four-colour procedure is carried out by simultaneously processing the "geographic" and "statistical" files, then placing the area symbols from the library using a programme and finally adding the legend file. The area symbols and the screens are generated on films by an automatic laser-plotting machine in order to produce the black, cyan, magenta and yellow master printing plates which are completed manually when necessary. Then follows the addition of the point symbols and the legend elements appropriate to each map, and finally the integration of the planimetric-relief-hydrographic base map. A proof is produced by the Cromalin process for inspection prior to four-colour printing.

BASIC PRODUCTS

The results of this procedure are displayed in two forms : a series of maps accompanied by tables of statistical data.

Maps

The basic tools are the land use maps with legends which immediately reveal two reading levels. At a first glance, the reader differentiates between the urban zones (bright colours with gradation, geometric area symbols), agricultural zones (cool colours, slack area symbols), natural zones (dull colours), coastlines (black area symbols), aquatic zones (on the hydrographic blue colour, figurative area symbols in cyan for the breeding zones and in magenta for the natural resources to be protected). Inside each of these groups, a more detailed examination (second reading level) makes it possible to find each legend item. At the technical level, the only elements added manually to that map are point symbols in magenta (discharges, isolated buildings) , embankments, the sheet title and commune names and boundaries on the black printing plate ; it is planned to digitize these items in order to plot them automatically. The outlines of the photo-interpretation zones, the legend lettering as well as the kilometric ticks are generated automatically on the same plate as the black area symbols.

The maps showing land status are, in certain ways, more complex because numerous themes are superposed.

The base is a legal map which includes town planning documents translated by colours recalling the land use (spaces allocated to urbanization, agriculture, natural zones), a forestry theme in magenta area symbols (land clearing forbidden, protected forest, forest perimeter fire-break), protected sites in black area symbols (parks, reserves, historic or other sites), maritime status in magenta or cyan area symbols.

It is completed by a monochrome land ownership map using screens and area symbols ; point symbols are added manually for the linear zones and small properties.

In order to obtain a first comparison between the legal texts and the actual use of the land, a summary land use map is also produced. The reduction of the scale from 1:25 000 to 1:100 000, the regrouping of the land use themes into seven classes (urban, agricultural, and natural zones, wooded country, marshy zones, marine breeding and natural resources) and the assembly from 3 to 8 sheets at 1:25 000 for each sheet at 1:100 000 takes place automatically with a group of programmes, so that the thematic plate of monochrome area symbols is produced directly without photo-engraving operations.

Statistics

The second type of document produced systematically is a list of communal statistics. To the population and housing data collected during the 1968 and 1975 national censuses are added the total areas of the themes for each commune by distinguishing between three different types of geographic zone :
(a) the actual littoral zone extending from the coast inland for a depth of 2 km, (b) a less sensitive zone from 2 to 5 km and (c) the hinterland beyond 5 km. These results are obtained by computer crossing of the digitized outline plates and the communal boundary files. The areas are printed in hectares.

DERIVED PRODUCTS

The advantages of the above procedure stem directly from file constitution and, in particular, from the raster-mode files. In addition to the fact that the acquired data are stored in perfect condition, all the information shown on a printed map is immediately usable for producing either a new thematic map or statistical results. In addition, the technical resources used enable one to have, whilst keeping to the four-colour process, a very wide range of colours and symbols whilst obtaining a graphic quality which exceeds the best traditional products. Finally, the printing scale can be selected as required and contiguous maps can be assembled very rapidly.

Cartographic products

A certain number of trial uses of the files have now been carried out.

For instance, it has been possible to select a theme or a group of themes by associating it with the assembling of several sheets and with a change of scale : this makes it possible to display a particular phenomenon or to present a synthesis of the space over a vast zone covering several sheets of the initial sheet line system.

By crossing themes obtained from maps printed at the same or different scales, one of the themes acting as a selective mask with respect to the other, one can display the interactions between different phenomena, such as legal provisions and the actual state of affairs. Thus it has been possible to study the degree of protection of natural spaces with respect to the diffuse urbanization due to tourist developments.

Statistical products

Another class of products is constituted by purely statistical outputs. These can be the equivalent, in the statistical field, of the cartographic documents described above but one can add :

(a) ratio calculations for determining a typology of communes or natural regions in accordance with a group of criteria (tourist, agricultural, or industrial vocation, etc.),
(b) integration of data taken from other French national files e.g. national censuses of population or agriculture, inventory of communal services and equipment, the construction file, business concerns and factories file, etc.

One thus constructs a communal statistics data base whose different components mutually enrich one another and unite to provide a better knowledge of the littoral and lead to an improved follow up of its evolution.

REVISION

The Inventory is planned on a five-year cycle. This decision led to the early inclusion of the revision aspect in the design of the production chain used for the reference operations based on 1977 aerial photography.

For the second generation, the photo-interpreters will have the reference map and the summer 1982 aerial photography at their disposal. The photo-interpretation overlay will be produced on a base map showing the topography and the outlines of the initial zones ; only those zones which have been modified between the two aerial surveys, either in their geometric definition or their thematic contents, will be redrawn. The compilation will thus be considerably reduced. That overlay will be digitized in the same way as in the initial procedure and the revision will be carried out by an entirely computerized procedure. Two land use files will then be available, one for the reference date the other corresponding to the current state. One will then be able to produce an up-to-date map and evolution maps.

The large number of themes involved excludes the representation of all the evolutions on a single map : some of them by their very nature are impossible to display or are of little significance. However, a major advantage of the digital production-line associated with raster mode mapping is the possibility of being able to automatically produce those evolution maps without undertaking a new interpretation by comparison of two the states and a new compilation for each type of evolution map ; the time gained and the money saved are appreciable.

In addition, all the statistical calculations can be carried out either in global percentages or more precisely by calculating the evolution matrix. These results, completely impossible to obtain with normal manual cartography, can guide the selection of the evolution maps to be produced.

CONCLUSION

The major project constituted by the Littoral Inventory forms part of a decisive stage in thematic cartography. The printed maps cover two basic functions (a) a function of synthesis, i.e. collection of data corresponding to a given moment, which particularly interests technicians and (b) a teaching function of information transmission by images to a larger public including those persons responsible for making decisions and formulating policy, regional development authorities, teachers and all persons concerned by the development of the littoral zone.

However, the cartographer is no longer the exclusive author and producer of a given map ; henceforth a map will result from the particular use of file or group of files via software and the cartographer must become a computer expert in order to design and develop those files and software so that he can make the best use of the mass of recorded data.

If the reference document, the one which contains all the data, is no longer a map but a digital file, the power of computers and automatic equipement will become available to the cartographer who can then rapidly produce many varied forms of output using representation modes which are as detailed as he requires.

DATA BASE MODELING TO DETERMINE IMPACT OF DEVELOPMENT SCENARIOS IN SAN BERNARDINO COUNTY

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ABSTRACT

The San Bernardino County project, completed in May, 1982, is one of four projects sponsored by NASA as part of the California Integrated Remote Sensing System effort. The project is a joint effort of NASA's Ames Research Center, the Environmental Systems Research Institute, the San Bernardino National Forest, and the San Bernardino County Planning Department. A major goal of the project was to demonstrate that Landsat data could be a useful component of a data base by functioning in unison with other elements to extract new and useful information. The project acquired and integrated a diverse range of data including Landsat-derived land cover, photointerpreted land use, terrain, soils, and geology. Models oriented towards County applications were developed to provide maps of areas suitable for urban growth, and to generate historical information on past growth through comparison of various data elements. Models oriented towards Forest Service applications were designed to generate and compare the impact of allowing unrestricted urban development around the National Forest fringe versus the impact of developing a fire protection zone (greenbelt) with restricted urban development. This application of the data base was developed partly as a result of a 1981 National Forest fire that consumed about 700 homes in the city of San Bernardino. The scenarios were compared through the use of fire hazard, erosion, water runoff, and urban and agriculture capability/suitability models.

INTRODUCTION

The San Barnardino County (SBC) Vertical Data Integration Study is one of four approaches to Landsat data integration studied by the California Integrated Remote Sensing System (CIRSS) Task Force. One objective of the SBC study was to examine the effectiveness of using private industry to aid local governments in their efforts to integrate geographic data. Towards this end, the San Bernardino project involved two government agencies and a private contractor, the Environmental Systems Research Institute (ESRI), in the construction and utilization of a data base. NASA's Ames Research Center maintained control of the project direction and of work involving classification of the Landsat data subsequently incorporated into the project's data base.

A major goal was to demonstrate that Landsat data could be a useful component of a data base by functioning in unison with other elements to extract new and useful information. A cornerstone of the CIRSS efforts was the concept of Vertical Data Integration. This concept refers to the integration of a range of separate data sets covering a single geographic area, as opposed to horizontal integration or the mosaicking of spatially adjacent data. The vertical integration concept stresses that the integration of data sets for a given area – data often held unshared by a variety of agencies – will have beneficial synergistic effects.

Both the San Bernardino National Forest (SBNF) and the San Bernardino County Planning Department (SBCPD) provided significant input and personnel time. A major test for this demonstration effort was to develop a data base that could be effectively used in yielding information important to these two agencies.

STUDY AREA

The project study area consists of the southwest corner of San Bernardino County, California. This area of roughly 750,000 acres (1200 mi. sq.) consists of the urban San Bernardino Valley, the brush and forest covered San Bernardino Mountains, and a portion of the Mojave Desert (Figure 1). Portions of the mountains are undisturbed wilderness, while much of the valley has experienced rapid development of residential and commercial properties. Natural land cover varies from valley grassland to hillside chaparral to mountain coniferous forest.

DATA BASE DESCRIPTION

In the project, a 39-layer data base (Table 1) covering the full study area was created. Some of these data were in digital polygonal and grid form, while others existed as unautomated map sheets. The data were all coregistered to the local state plane coordinate system and gridded into four-acre cells, with data being automated as required. Additionally, small area data bases were generated using components of the full area data base (Tables 2 and 3). The small area data bases were gridded into one-acre cells and used for localized applications analyses. 1976 and 1979 Landsat land cover data were components of each of the data bases. The Landsat data classification decisions were influenced by a number of the data base elements. The rationale is that Landsat data cannot only be useful within a data base, but that a data base can also be useful in categorizing the Landsat data (Likens and Maw, 1981.) It should also be noted that the full and small area data bases each contained photointerpreted 1974 and 1979 land use data. Land use is context oriented and fundamentally different from (though similar to) land cover; these data should not be confused as to origin and type.

Table 1. Elements of full study area data base.

1. Row
2. Column
3. Subarea
4. Valley Terrain Unique Number
5. SBNF Terrain Unique Number
6. Valley Map Module Number
7. Valley Terrain Unit Number
8. Valley Land Cover
9. Valley Geologic Type
10. Valley Slope
11. Valley Landform
12. Valley Soils
13. Valley Geologic Hazards
14. Valley Flood-Prone Areas
15. Valley Ground Water
16. SBNF Map Module Number
17. SBNF Terrain Unit Number
18. SBNF Land Cover
19. SBNF Geology
20. SBNF Slope
21. SBNF Landform
22. 1974 Land Use
23. 1979 Land Use
24. General Plan
25. Census Tracts
26. Valley Roads
27. Valley Railroads
28. Valley Streams
29. Valley Fault Lines
30. 1976 CDF Landsat
31. Elevation (DMA)
32. Slope Aspect (from elevation)
33. Slope (from DMA elevation)
34. 1976 Landsat Land Cover
35. Change Mask (Landsat)
36. 1979 Landsat Spectral Classes
37. 1979 Landsat Land Cover
38. Valley Soils
39. Valley Soils K Values

Table 2. Yucaipa Area Data Base

1. Row
2. Column
3. Study Area
4. Valley Terrain Unique Number
5. Valley Map Module Number
6. Valley Terrain Unit Number
7. Valley Land Cover
8. Valley Geologic Type
9. Valley Slope
10. Valley Landform
11. Valley Soils
12. Valley Geologic Hazards
13. Valley Flood-Prone Areas
14. Valley Groundwater
15. 1974 Land Use
16. 1979 Land Use
17. General Plan
18. Census Tracts
19. Valley Roads
20. Valley Railroads
21. Valley Streams
22. Valley Fault Lines
23. 1976 CDF Landsat
24. Elevation (DMA)
25. Slope Aspect (from elevation)
26. Slope (from DMA elevation)
27. 1976 Landsat Land Cover
28. Change Mask (Landsat)
29. 1979 Landsat Spectral Classes
30. 1979 Landsat Land Cover
31. Valley Soils
32. Valley Soils K Values

Table 3. Fire Buffer Greenbelt Data Base.

1. Row
2. Column
3. Study Area
4. Valley Terrain Unique Number
5. SBNF Terrain Unit Unique Number
6. Valley Map Module Number
7. Valley Terrain Unit Number
8. Valley Land Cover
9. Valley Geologic Type
10. Valley Slope
11. Valley Landform
12. Valley Soils
13. Valley Geologic Hazards
14. Valley Flood-Prone Areas
15. Valley Groundwater
16. SBNF Map Module Number
17. SBNF Terrain Unit Number
18. SBNF Land Cover
19. SBNF Geology
20. SBNF Slope
21. SBNF Landform
22. 1974 Land Use
23. 1979 Land Use
24. General Plan
25. Census Tracts
26. Valley Roads
27. Valley Railroads
28. Valley Streams
29. Valley Fault Lines
30. 1976 CDF Landsat
31. Elevation (DMA)
32. Slope Aspect (from elevation)
33. Slope (from DMA elevation)
34. 1976 Landsat Land Cover
35. Change Mask (Landsat)
36. 1979 Landsat Spectral Classes
37. 1979 Landsat Land Cover
38. Valley Soils
39. Valley Soils K Values
40. SBNF Soils
41. SBNF Soils K Values
42. SBNF Soils

YUCAIPA SMALL AREA STUDY - COUNTY ORIENTED ANALYSIS

The Yucaipa area is on the relatively rural fringe of the more densely populated east San Bernardino Valley. Pressure to develop the Yucaipa area has resulted in tentative approval for a waste treatment facility which will allow the denser development as well as the conversion of presently unimproved acreage. Since the Yucaipa area is unincorporated, it is one of the areas where the County has a mandate to ensure orderly development.

To determine which areas are more likely to be developed in the future, an urban development capability/suitability model was used with the integrated Geographic Information System (GIS) data base to identify those areas most capable of supporting construction. Landsat data was not used in this initial model. The resulting data file and map output rank each cell according to its relative capability/suitability to support development (Figure 2). The major geographic constraints such as steep slopes, flood-prone areas and high fire hazards are rated very low capability/suitability for urbanization. The presence of existing urban land use (photointerpreted) indicates the presence of infrastructure (roads, water service, etc.). Increasing distance from 1979 existing urban land use was therefore used to decrease the suitability of land for development.

Areas which the model designated "high capability/ suitability" are without major constraints, on gently sloping land, near existing urban uses, and are consistent with those areas designated for moderately dense development by County planning documents.

The non-Landsat or GIS only model generated above was used as a base for comparison to an identical model that incorporated only one other data layer, namely, 1979 Landsat land cover data. The GIS + Landsat model map displays several significant differences when compared to the output of the GIS-only model. The most apparent difference is the presence of "very high" capability/suitability assignments on the integrated (GIS + Landsat) model. The development in the area consists of structures fronting on streets (1/4 to 1/2 mile long) and large acreage of grassland within the residential block. The higher resolution of the Landsat land cover data (1 acre vs. 10-acre minimum mapping units, despite the quantization of all data into one-acre grid cells) allowed the undeveloped lands surrounded by residential development to be pinpointed as prime areas for development infill.

A correlation analysis between the two models was used to determine that the Landsat data in the second model accounted for about 10% of the variance in the model output. In other words, the inclusion of Landsat data added about 10% more variance over that present in the GIS model.

The land cover and land use data were also used to conduct change analyses within the Yucaipa area. However, these are not discussed in detail here because they did not involve modeling efforts utilizing major portions of the data base. The reader is directed to Likens et al. (1982), and Hodson and Christenson (1982), for in-depth descriptions of change detection efforts undertaken.

GREENBELT SMALL AREA STUDIES – FOREST SERVICE ORIENTED APPLICATIONS

In the summer and fall months, the brush and grass lands of the San Bernardino National Forest become very susceptible to fires. Such fire hazards are exacerbated by the large number of people in and about the forest. Fires within the SBNF are a hazard not only to the forest, but also to the extensive urban areas along its southern fringe. As a case in point, a 1981 fire moved out of the National Forest to destroy about 700 homes in the city of San Bernardino. Consequently, the SNBF has examined the possibility of establishing a fire protection zone, or "Greenbelt," along the forest fringe.

NASA determined that an evaluation of the impacts of greenbelt and non-greenbelt development strategies would be a useful demonstration of data base utility. This resulted in ESRI working with the SBNF to evaluate the fire hazard, erosion, and runoff results of each strategy using data base modeling. An initial task generated a small area data base for an area within which greenbelt policies might be established. Using a broad interpretation of SBNF guidelines [described by Bridges (1982)], we extracted a strip roughly one mile wide along most of the length of the slope break between the southern extent of the Mountains and the Valley floor. The resulting data base was gridded into one-acre cells.

The greenbelt and non-greenbelt management strategies were evaluated through the projection of two development scenarios: a continuation of present development trends (non-greenbelt scenario), and that of restricted urban development and increased agricultural use (greenbelt scenario). Initially, the small area data base was used to model fire hazard, erosion, and runoff conditions as of 1979, or before any scenario was hypothesized (also before the 1981 fire). Concurrently, the greenbelt scenario was formulated as an agriculture capability/suitability model that hypothesized no further urban expansion, and a non-greenbelt scenario formulated as an urban development capability/suitability model. The output from the two capability/suitability models were applied as modifiers to the outputs from the fire hazard, erosion, and runoff models to yield their projections. A diagram of the overall process is shown in Figure 3, with summaries of model inputs in Table 4 and output acreages in Table 5.

Table 4. Greenbelt model inputs.

Fire Hazard – 1979 Landsat Land Cover, Slope
Runoff – Soil Capability Class, Slope
Erosion – Soil K Value, Slope

Table 5. Impact Comparisons.

	Non-Greenbelt	Greenbelt
Fire Hazards		
Very high	27,080	2,340
High	7,747	23,227
Moderate	6,766	5,400
Low	7,182	5,665
Very low	5,995	18,138
Runoff		
Low	6,422	11,027
Moderate	10,859	10,681
High	11,582	8,123
Very high	25,829	24,861
Water	78	78
Erosion		
Very low	7,668	16,157
Low	7,442	4,287
Moderate	5,329	3,174
High	9,718	7,805
Very high	24,535	23,269
Water	78	78

As expected from the intent of greenbelt designation, application of agricultural use significantly reduces fire hazards for the area (Figures 4 and 5). A few areas of high slope remain designated as high fire hazard. If no greenbelt buffer is designated, urbanization of the area will extend fire hazard conditions southward into the valley areas. As expected, little runoff difference is calculated on the steeper slopes, as these areas are not projected to support dense development.

Designation of a greenbelt fire buffer along the steeper slopes and to the valley would have little impact on existing runoff rates, but could increase runoff on moderate slopes. Urban development in the valley would also increase runoff in those locations, while agriculture would reduce runoff. Increases in erosion are expected to occur in areas of low and moderate density urbanization. Increased erosion presents a control problem in these locations, and could be addressed by appropriate grading and runoff controls. Erosion also presents a hazard to development along the base of the steeper slopes where mud flows often occur during rainfall following a burn. This hazard could be reduced by locating the greenbelt fire buffer in these locations.

A critical need to have good slope data was noted in the generation of the model products. The Landsat land cover data was used as inputs into only the urban and agriculture capability/suitability models, and the fire hazards model. In contrast, slope information was a critical input into all five of the greenbelt-oriented models. In the greenbelt small area data base there are two slope data layers, one created through slope calculation Defense Mapping Agency (DMA) digital elevation data quantitized (after processing by the Jet Propulsion Laboratory for Ames for an earlier project) into 40 foot elevation increments, and the other from slope polygonal data digitized from maps, and converted into 1-acre grid cell format. In testing two slope data sets as inputs into the calculation of fire hazard, it was noted that the DMA based data (Figure 6) introduced a significant amount of artificial terracing or contour effect into the product that was not present with the polygonally based data. Artificially abrupt slopes resulting from 40-foot elevation differences between adjacent grid cells in near level areas resulted in this contour effect in the DMA based slope data.

The impact model outputs provide graphic illustration of the location and severity of impacts expected to result from designation or non-designation of a fire buffer greenbelt within the mapped study area. These models provide information useful to the planning of activities and location of boundaries of the proposed greenbelt. While the models used are one of several possible methods for impact evaluation, their results are consistent with known conditions and historic concerns within the study area.

CONCLUSION

Vertical data integration allows a variety of data types to be evaluated simultaneously and provides a depth of analysis capability not possible with single data sets. Inconsistencies between data sets can become apparent and can be dealt with effectively, producing a more consistent data base. It was demonstrated that Landsat land cover data could be successfully used with other data to derive important planning information. The Landsat data was found to have higher spatial resolution than other data elements found in the data base (one-acre pixels versus 10 to 40+ acre minimum mapping units). Also, the Landsat data easily encompassed the full geographic extent of the study area, while most other data sets used were found to be significantly smaller in geographic extent. This was in part a result of focussed interest of individual agencies on specific portions of the study area, rather than the whole. The small data size of many other GIS data bases leads to the conclusion that many planning agencies and other data base users are accustomed to working with either smaller geographic areas or with courser resolution data than those in the remote sensing field. The use of Landsat data as a component in data base modeling can make possible the generation of products covering larger geographic areas, as products with greater spatial detail, than might be possible through the sole use of other geographic data base elements.

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Likens, W. and Maw, K., 1981. Hierarchical Modeling for Image Classification. Proceedings of the Pecora VII Symposium, Sioux Falls, S. Dakota, p. 290-300. American Society of Photogrammetry, Falls Church, Va., 1982.

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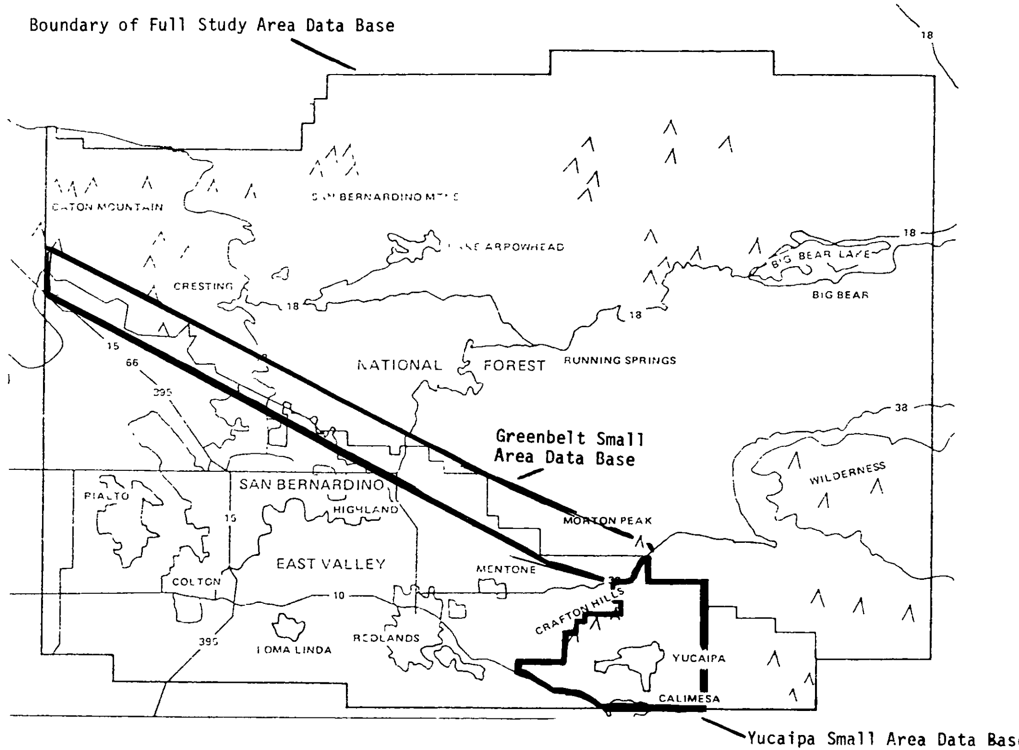

Figure 1. Study Area

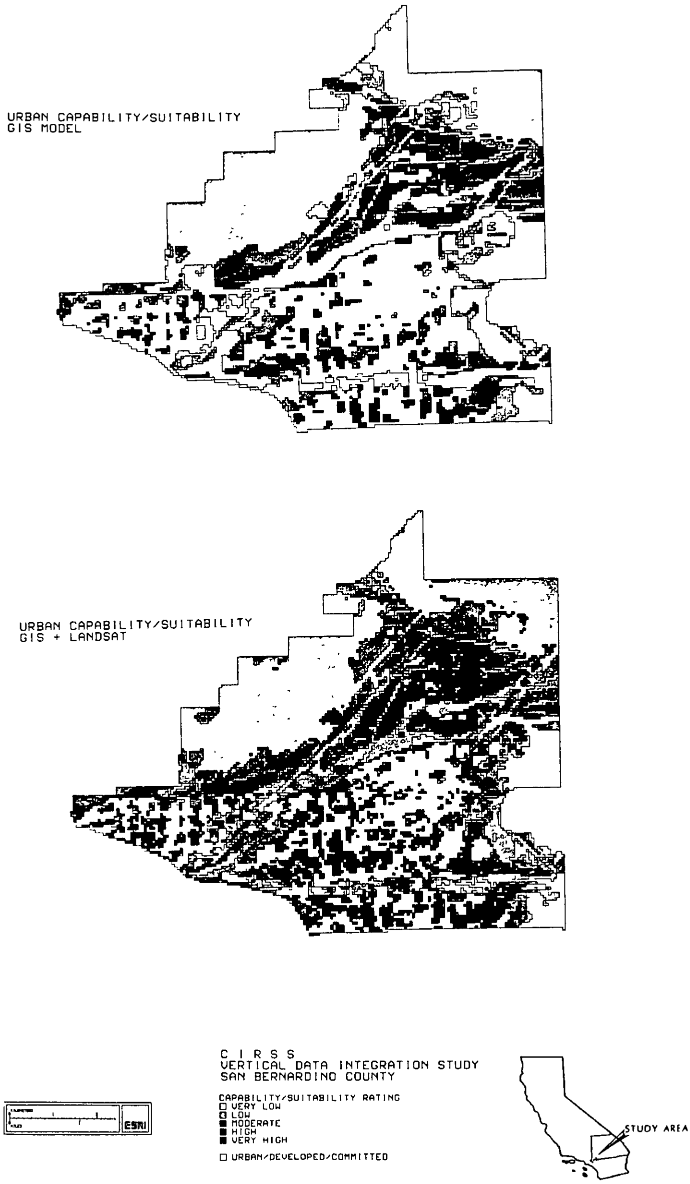

Figure 2. Yucaipa area urban capability/suitability.

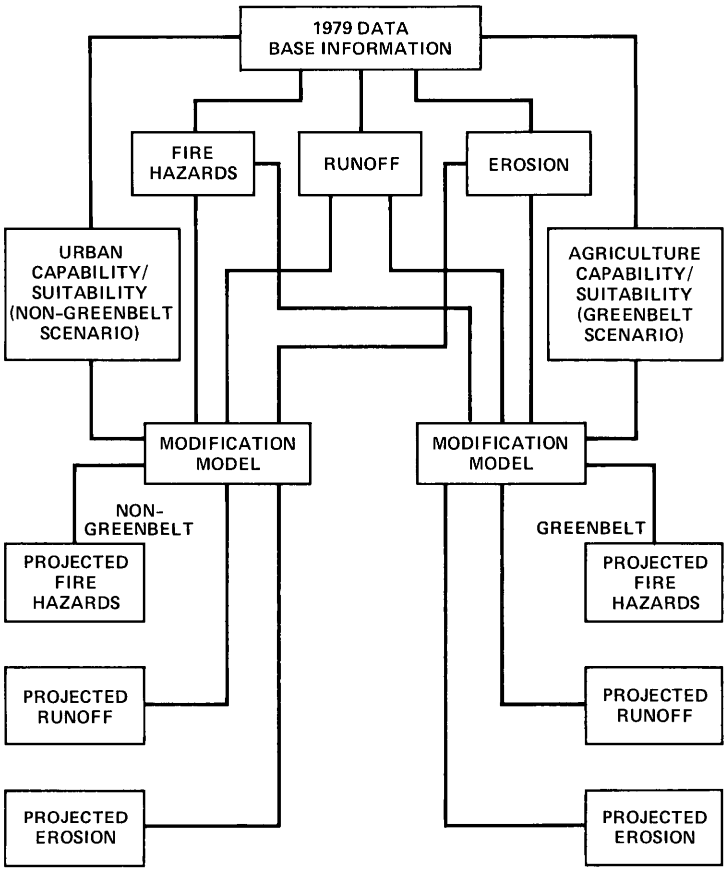

Figure 3. Greenbelt analysis flow.

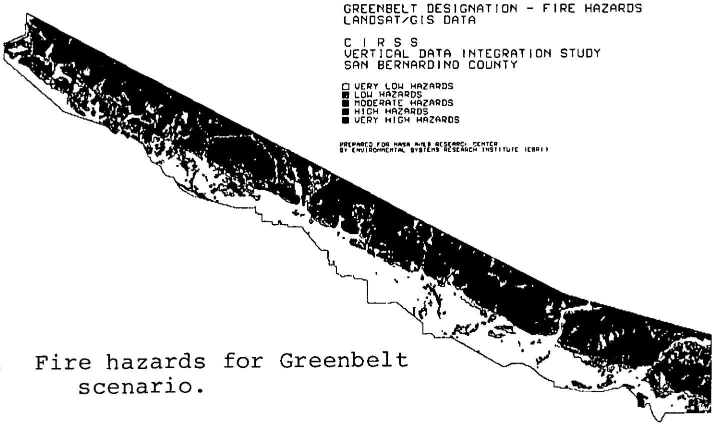

Figure 4. Fire hazards for Greenbelt scenario.

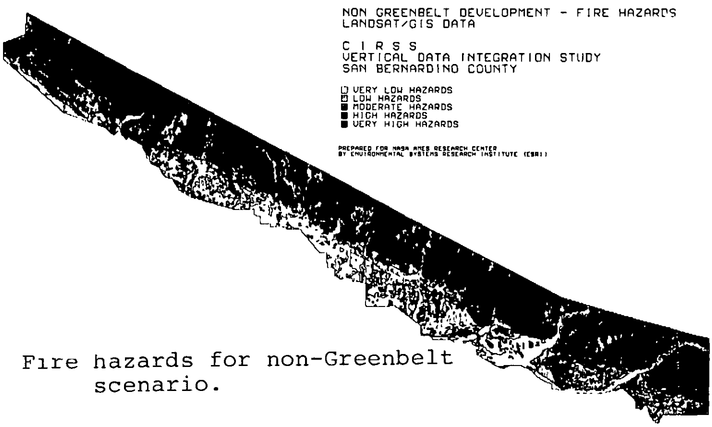

Figure 5. Fire hazards for non-Greenbelt scenario.

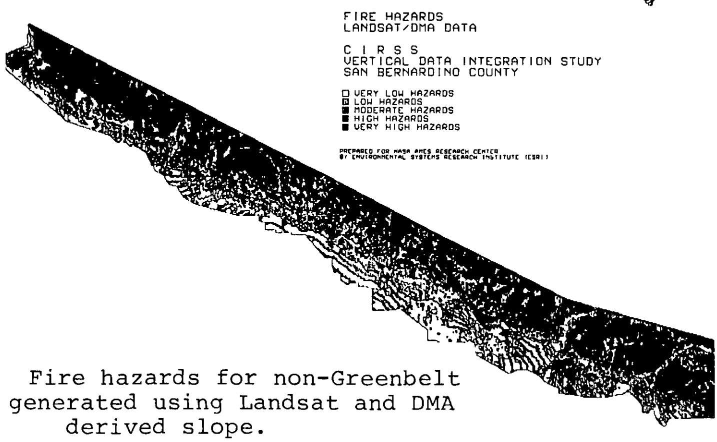

Figure 6. Fire hazards for non-Greenbelt scenario generated using Landsat and DMA derived slope.

COMPUTER ASSISTED CHART SYMBOLIZATION AT THE DEFENSE MAPPING AGENCY AEROSPACE CENTER

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ABSTRACT

Computer assisted cartographic techniques are being used at the Defense Mapping Agency Aerospace Center (DMAAC) for chart symbolization of digital data for prototype production of charts. These digital data are collected by employing different computerized collection systems, one system being the Automated Graphic Digitizing System (AGDS). Computer symbolization of the digital data is accomplished by the Graphic Line Symbolization System (GLSS). The GLSS software generates plotting instructions for drafting the symbology according to chart specifications and plots on film, paper, mylar or by the electrostatic plotter. By using GLSS software, 50 percent of the man-hours required by the negative engraver have been saved. The digital data from the previously mentioned systems can be archived for permanent storage and updated as needed to produce revised charts.

INTRODUCTION

The Defense Mapping Agency Aerospace Center (DMAAC) is producing prototype charts from digital data. The digital data for these charts are collected, edited, and color separated in-house by the Automated Graphic Digitizing System (AGDS). The cartographic features from the digital data are symbolized according to chart specifications and plotting instructions for them are generated by the Graphic Line Symbolization System (GLSS). The GLSS software saves 50% of the man-hours normally used by the negative engraver for building lithographic color separation plates. The symbolized data from GLSS is archived for later chart revisions.

AUTOMATED GRAPHIC DIGITIZING SYSTEM

The Automated Graphic Digitizing System (Broomall Industries, 1979) is a system designed for data collection, interactive editing, and color separation of compilation overlays (The referencing of Broomall Industries does not constitute endorsement by DMAAC). The three main subsystems of the AGDS system are: the scanner, the vectorizer, and the edit tag subsystem. (Figure 1).

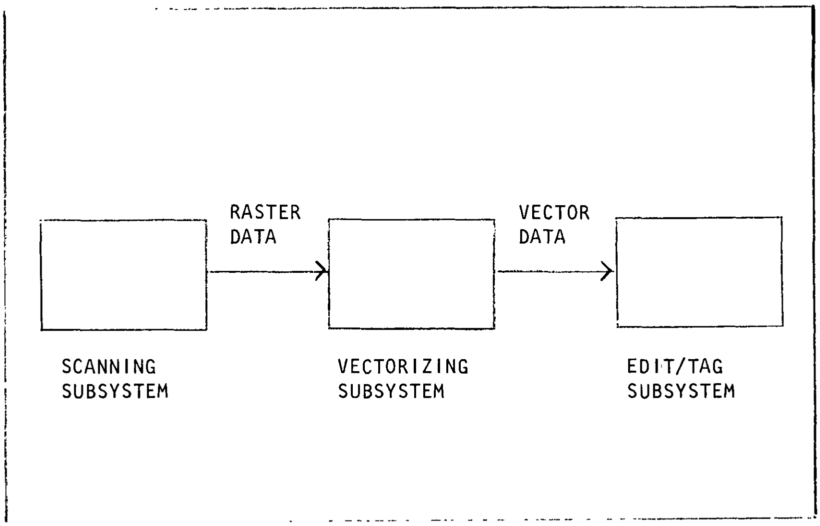

Figure 1. Automated Graphic Digitizing System (AGDS)

The laser scanning subsystem is used to scan compilation overlays outputting the data in raster format. The scanning subsystem has a resolution of 1 mil with an accuracy of 4 mils. The vectorizing subsystem converts the raster data to vector format. Once the scanned overlays are in vector format, the data are input to the edit/tag subsystem. The cartographer at the edit/tag subsystem has the capability to interactively edit the data, create sub files from the data, and to mathematically transform the separate overlays to the compilation projection base. Common points between the individual overlays and projection base are used for controlling the overlays to the projection. After the cartographer has transformed the overlays to the projection, he interactively separates and inserts unique feature identification codes (FIC) to features according to their unique color separation. For example, drainage would be displayed on the blue color separation whereas cultural features would be displayed on the black separation. The color separations correspond to the colors for the lithographic printing plate. The FIC, or tag number corresponds to a specific set of previously defined instructions for feature symbolization.

After the data has been separated at the edit/tag subsystem, an output tape is generated for off line chart symbolization by the GLSS Software.

GRAPHIC LINE SYMBOLOGY SYSTEM

The GLSS software is to provide the cartographer with a chart product that shows cartographic features, such that one feature can be easily distinguished from the other.

The GLSS software converts line centered data to a specific product format which depends upon the chart specifications being used for the final chart compilation. The product format is generated by a graphic film (photo) plotter.

GLSS was originally developed by the PRC Information Sciences Company (PRC, 1976) under contract to The Rome Air Development Center (RADC) (The referencing of PRC Information Sciences Company does not constitute endorsement by DMAAC). DMAAC has converted and modified the original source code to process in batch mode on the main frame computer system. DMAAC is currently in the process of converting the main frame program to process on a mini computer System.

The system design of GLSS depicted in figure 2 consists of: 1) symbol specification file, 2) job control data file, 3) line centered feature input file, 4) symbolization processing unit, 5) symbol generated output tape, and 6) a processing summary report.

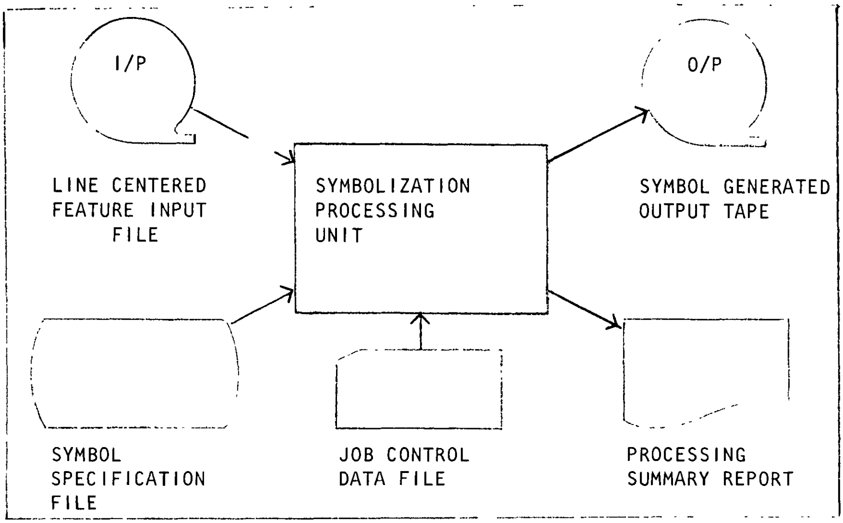

Figure 2. System Design of GLSS

The symbol specification file (SSF) from Table 1 consists of procedures and symbol pieces input to the symbol processing unit for generating chart symbology. There are procedures and symbol pieces defining each cartographic feature. The GLSS software was originally designed for processing symbology with a maximum of eight symbol pieces per feature. DMAAC has expanded this software restriction. The software can currently process 20 symbol pieces per feature. Table 1 is an example of the procedures and symbol pieces required to symbolize a perennial drain. Notice the file is organized by the headings: Feature Identification Code (FIC), Conformal or Non-Conformal, Type of Symbol, Lineal or Flashed Symbol, Symbol Size, and Symbol Line Weight. The FIC code is a unique number taken from the DMA Standard

Cartographic Feature Digital Identification Catalog. The Catalog contains a listing of possible chart symbology with its corresponding FIC number. A fifth digit is sometimes appended to the FIC number to relay instructions to the specialized ticking routine of the symbol processing unit. The conformal/non-conformal identifier instructs the symbolization routine to either draw point symbology parallel to slope of line (conformal) or parallel to plotter axis (non-conformal). The type of symbol identifies to the symbol processing unit which symbolization routine to use. All symbol pieces with an F are to be flashed by GLSS while those which are lineal or blank will be drawn in line mode. Symbol size and symbol line weight are parameters used by the symbolization routines. The actual symbolization process will be discussed under the symbolization processing unit.

Table 1. Symbol Specification File

Feature Identi- fication Code	Conformal Non- Conformal	Type of Symbol	Lineal (blank) Flash(F)	Symbol Size (inches)	Symbol Line Weight (inches)
4347	CON	DASH		.193	.007
	CON	SPACE		.029	.000
	CON	DOT	F	.007	.007
	CON	SPACE		.025	.000
	CON	DOT	F	.007	.007
	CON	SPACE		.025	.000
	CON	DOT	F	.007	.007
	CON	SPACE		.029	.000
EOSYMB					

The job control file in figure 2 provides the user with various options so that he can either create new symbol specification files, list the feature headers with descriptive information about the feature, or plot the line centered feature file according to chart specifications. New symbol specification files can be developed by employing different combinations of the specialized routines (Table 1). Flashed symbols can also be used to complement the specialized routines. By option, the symbolized features can be plotted on the Gerber film plotter, the Versatec electrostatic plotter, the Xynetics plotter, or the Gerber pen plotter. The Versatec, Xynetics and Gerber pen plotters are used for making proof plots. The function of the proof plot is to insure there are no symbolization errors due to improper tagging at the AGDS system. Upon acceptance of the proof plot, a final film plot is created which is used in the process of building a lithographic press plate.

The line centered feature input file from figure 2 contains digital cartographic features collected by the AGDS scanner. Each cartographic feature has an associated header record with a FIC code linking that feature to the symbol specification file. From GLSS, the symbol generated output tape contains all of the plotting instructions for actually drafting the chart symbology by a plotting device. At the termination of each GLSS processing program there is a processing summary report. This report includes such descriptive information as: the FIC numbers, the number of (x,y) points per feature, the sequence number for each feature, I/O processing actions, symbolization routines used for processing, and the number of points processed and deleted.

The symbolization processing unit of GLSS referenced in figure 2 is the heart of the program. In general, GLSS consists of a monitor or driving routine, data smoothing routines, data input routines, data output routines, and the symbolization processor. There are many specialized routines under the command of the symbolization processing unit which symbolize line centered cartographic feature data or cartographic point data. When using the Gerber photo plotter option, some point symbology is drawn by line drawing commands while other more complex symbols are flashed on the film at the desired (x,y) location. The point symbology drawn by the line drawing commands must have a unique subroutine for generating the plotting instructions. The more complex symbols requiring artistic flair and variable line weights are flashed. It is easier to flash them than develop subroutines which possess the artistic flair and capability to plot variable line weights. The most complex symbols, which are seldom used, are manually placed on the film positive by the cartographer.

Specialized routines including description for the symbolization processor are listed in Table 2.

Table 2. Specialized Routines

LINE -	Routine generates a line using line weight from SSF
DASH -	Routine generates a dashed line with line weight and dash length, coming from SSF
SPACE -	Routine to generate a space along a linestring with distances taken from SSF
TICK -	Routine which generates a tick along linestring; the tick is perpendicular to the linestring
HALFTICK -	Routine generates a tick perpendicular to linestring; however, doesn't intersect and the side of line to be ticked is determined by the 5th and most significant digit of the FIC code
ALTERNATING HALFTICK -	Routine generates alternating ticks on both sides of the linestring

DOT -	Routine drives plotter head to desired (x,y) location and flashes dot with diameter of dot taken from SSF
CIRCLE -	Routine generates a circle of specific size and line weight from a specific point
CROSS -	Routine generates a cross over specific point either conformal to slope of line or parallel to plotter bed
SQUARE -	Routine generates a square centered over a specific point
PYRAMID -	Routine generates a pyramid over a specific point
MINE SYMBOL -	Routine generates a mine symbol over a specific point

The processing scenario (Figure 3) for symbolizing a cartographic feature such as a perennial drain would be as follows. The GLSS driving routine would transfer control to the input routine. The input routine would read the feature header and pass the FIC code to the feature correlation routine. The feature correlation routine looks up the FIC code from the symbol specification file and, after positive correlation, program control is passed to the symbol routine which in turn invokes the specific specialized routine for performing the specialized functions indicated by the SSF file. For the perennial drain (Table 1), the plotting commands on the plotting output tape would be (dash, space, dot, space, dot, space, dot, space, dot . . .) until the entire linestring had been symbolized using this repetitive pattern. Program control would then pass to the input routine and the next cartographic feature would be read and symbolized with the process continuing until all features have been processed.

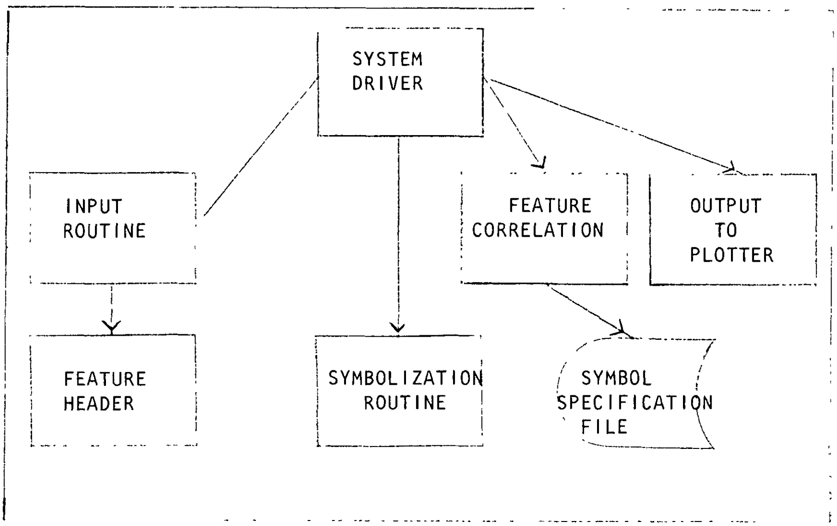

Figure 3. Processing Scenario for GLSS Symbolization

FILM POSITIVE PLOTS FROM GLSS

To this point, the collection and processing of digital cartographic data through AGDS and GLSS systems have been discussed. Now let's view some subplots taken from a full scale production chart. Figures 4 through 8 present symbolized plots for the following color separations: contours, drainage, roads, railroads, and radar significant analysis code (RSAC). Each subplot encompasses the same geographic area. The cartographic features for each subplot are plotted according to chart specifications. Figure 9 shows a composite registration of the film positives.

Figure 4. Contour Separation

Figure 5. Drainage Separation

Figure 6. Road Separation

Figure 7. Railroad Separation

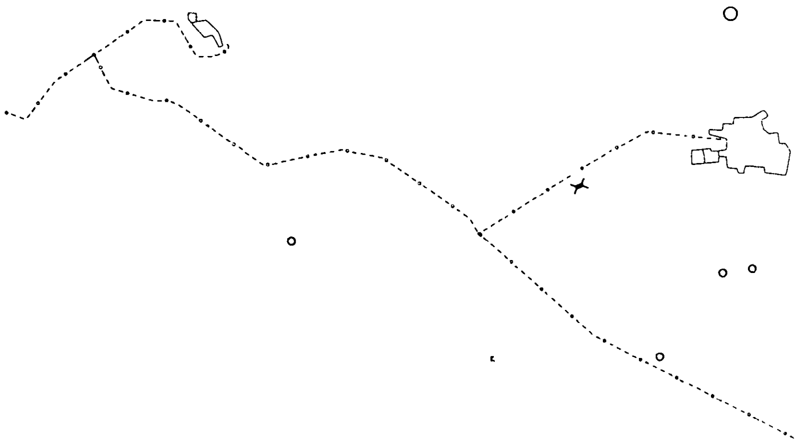

Figure 8. RSAC Separation

Figure 9. Composite of Separations
in Figures 4 through 8

The symbolized film positives from GLSS eliminate the need for the negative engraver to extensively hand engrave symbology on scribe cote. The engraved scribe cote is used for making photo negatives. The photo negatives are used for creating a lithographic press plate.

SAVINGS FOR THE NEGATIVE ENGRAVER

By eliminating the need to manually engrave most chart symbology, the negative engraver can save 50% of the manhours he would need to engrave the chart. For a particular prototype production chart, the engraver time required to scribe symbology and prepare the chart for printing was 430 manhours. To color separate the same prototype chart using digital data and GLSS software for symbolization required only 170 manhours from the negative engraver. Additional savings would be made for smaller scale, larger format charts.

ARCHIVAL OF DIGITAL DATA

The digital data for the prototype charts can be archived in a data base for later chart revision. A method for the archival of digital data would be to store the data in line centered linestring, or segment/node format. In this format, each cartographic feature would contain its attributes, including the FIC code in its descriptive header. For chart revisions, the simplification and classification or editing, tagging and merging of data sets could be done interactively on the AGDS edit/tag subsystem. After the data sets are edited and tagged, they must be merged according to their unique separations, then symbolized through GLSS again.

CONCLUSION

Computer assisted chart symbolization at the Defense Mapping Agency Aerospace Center is approaching production status. There are some restrictions which need to be further developed in GLSS. GLSS needs to process a larger set of point symbology. GLSS needs to have the capability of chart generalization, scale change, and data transformation from one projection to another. Interactive cartography through graphic work stations such as AGDS edit/tag subsystem are being exploited. In the future, chart production and revision will be supported from a digital cartographic data base. The data base will come from a variety of collection systems.

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1. Broomall Industries, Inc.; 1979; "Developer of the Automated Graphic Digitizing System," Broomall, Pennsylvania.

2. PRC Information Sciences Company; 1976; "Graphic Line Symbolization System," McLean, Virginia.

TITLE: SOFTWARE FOR THREE DIMENSIONAL TOPOGRAPHIC SCENES

AUTHORS: Joseph A. Honablew - U.S. Army Engineer Topographic Lab.

Joseph J. Schlueter - Defense Mapping Agency Hydrographic/ Topographic Center

Arthur A. Noma - Defense Mapping Agency Hydrographic/ Topographic Center

ABSTRACT:

The paper discusses the current capability for portraying three dimensional topographic scenes at the Defense Mapping Agency Hydrographic/Topographic Center and a background of its current usage and potential applications. A number of illustrations of scenes produced using Digital Terrain Elevation Data (DTED) and overlayed Digital Feature Analysis Date (DFAD) will be presented. Planned enhancements will be discussed with illustrations of type of results to be produced.

INTRODUCTION

The nature of the cartographer's work involves portraying geographic information about the three dimensional earth on a two dimensional medium. The topographic map represents a highly abstracted representation of the earth, and a map user needs well-defined map reading skills to use the map effectively. In particular, a map user needs considerable skill to read contours, visualize terrain, and orient himself with respect to the map and his surroundings. For many people, however, interpreting contours is a difficult task.

For nearly three decades, the Defense Mapping Agency Hydrographic/ Topographic Center (DMAHTC) and the U.S. Army Corps of Engineers, Engineer Topographic Laboratories (ETL) have been developing and using digital topographic data bases to support a variety of defense requirements. Since most of these data bases directly refer to attributes portrayed on topographic maps, both organizations are looking at ways to use digital information to supplement the map reading process. One approach is to provide three dimensional perspective graphics of digital elevation and planimetric data to the map user. This presentation on perspective graphics from digital topographic data reviews efforts by DMA and ETL to develop reliable graphic software, describes the existing production software capability at DMAHTC, and provides a projection on the future research and development efforts supported by both organizations.

DEVELOPMENT TOWARD PERSPECTIVE SCENES CAPABILITY

DMAHTC and its predecessor organizations, the Army Topographic Command and the Army Map Service, have long been engaged in efforts to develop capabilities for rapid portrayal of three dimensional topographic information. One of DMA's original products was (and still is) the well known three dimensional relief map which depicts three dimensional characteristics of topography with a scaled model of the Earth's surface. This product gained popular use during the late 1940's and early 1950's when it was produced in quantities needed to support military needs (Noma, 1959).

The relief maps were produced under a completely manual process that called for carving into a layered wax block. Based upon a need for a faster, more cost effective way of producing these relief maps, efforts were initiated in the late 1950's to develop a system to automate the process. The approach used was based upon experiments on terrain profiling and the potential of devising a method of digitally controlling the motion of a numerically controlled milling machine. The developed procedure called for collecting contours and other key terrain data, interpolating a complete array of elevation values, and then using these values to control the motion of an automatic milling machine (Noma, 1959). The key result of the effort to automate relief model making was the creation of the capability to manipulate and display an array of terrain data. With the resulting production system developed and operating by 1965, DMA collected data for most of the 48 contiguous United States from 1:250,000 topographic maps by 1974 (Noma, 1974).

At the inception of the effort, when DMA determined that it was feasible to collect and process digital terrain data, the idea of portraying topography as three dimensional views followed. The facility to represent terrain as an array of numerical values; along with the computer's ability for rapid calculation and the advent of reliable, digitally controlled plotting devices, provided the basis for development of software for producing transformed terrain views.

One of the early operational applications of three dimensional terrain scenes was for planning the 1972 Apollo 17 Lunar Module Landing. DMA was asked to provide data around potential landing site areas for use as input into a program for generating panoramic views. The site data was digitized and processed by DMA and then forwarded to Bell Laboratories which produced the views. The software used to produce these scenes, called TOPORAMA, was developed by Bell Laboratories under a contract with the National Aeronautics and Space Administration (NASA) (Taylor, 1972). It consisted of a set of programs which translated terrain data into plot lines, producing a perspective panorama and converting topographic data to a form that displayed the "terrain as it would be seen by an observer near or on the lunar surface." The objective of this program was "...to brief the astronauts on what the surface is like," and where the "...feeling for the surface comes from thinking of the surface as consisting of two sets of parallel lines, the two sets being perpendicular to each other, and projecting these lines onto a plane or cylinder. The convergence of the projected lines results in an image similar to a photograph" (Wynn, 1972)

Recognizing the potential use of the software for terrestrial applications, DMA obtained the software from NASA in 1974. Using TOPORAMA on the Univac 1108 computer, some demonstration scenes were produced as experimental graphics for military applications. Using the grid network as a base, planimetric features were then added manually to the scene by a cartographer to produce an enhanced view of the terrain. The resulting scene of Figure 1 was benchmarked as the target result which DMAHTC hoped to attain through automated means.

The TOPORAMA software had a number of restrictions on the input sequence of the terrain file and the location of the observer relative to the data. Also, the processing time to produce a scene was quite high. DMAHTC and ETL attempted to refine and enhance the software for general use, and to add basic planimetry plotting capability. However, because of the inherent logical deficiencies and inconsistancies in TOPORAMA, as well as the lack of good documentation, the effort was abandoned.

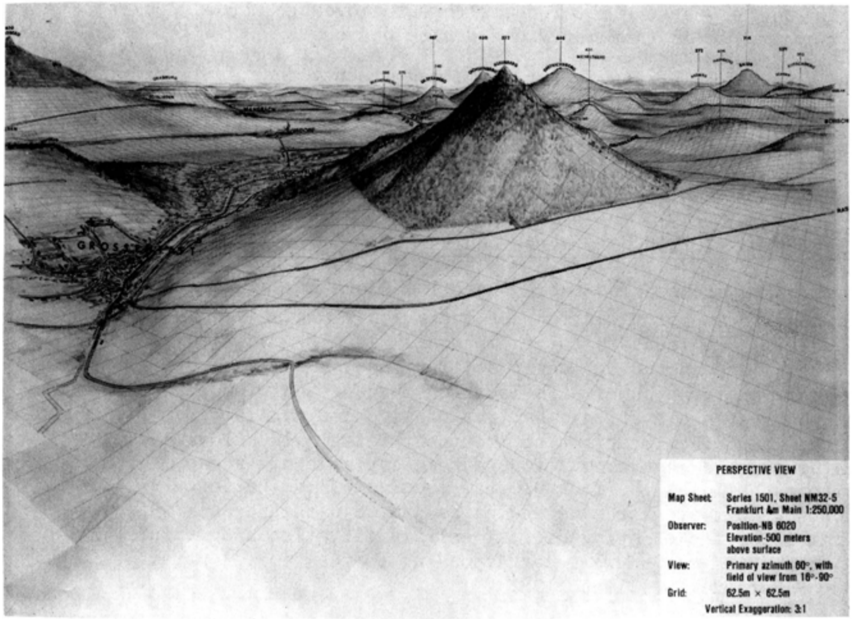

Figure 1. Enhanced TOPORAMA Scene

DMAHTC and ETL subsequently launched a new effort in 1979 to develop software that was specifically designed for DMAHTC's potential requirements and especially suited for use with DMA digital data. This software, the Perspective Plotting Software, was developed for DMA through a research and development project by ETL. The work was performed under a contract arrangement with the Electromagnetic Compatibility Analysis Center (ECAC) in Annapolis, Maryland (Scillian, 1981).

CURRENT PERSPECTIVE SCENES CAPABILITY

DMA Digital Data Bases

DMA currently produces a variety of digital data bases to support various requirements. The data bases vary in format from vector (digitized linework) to matrix (elevation arrays) depending on the user's specifications. In general, they are designed to coincide with the scales and specifications of map sheets produced by the Agency. Of the digital data bases produced at DMA, the most prevalent products are DMA-Standard Digital Terrain Elevation Data (DTED) and DMA-Standard Digital Feature Analysis Data (DFAD), which are produced independently for specialized purposes that do not coincide with the needs of data bases for visual displays. The data bases were chosen for perspective views, however, because of their wide areal coverage, current availability, and general acceptance.

DMA-Standard DTED is a matrix formatted product which is stored on magnetic tape as a series of geographically spaced, south-north directed profiles. Each profile record consists of elevation posts also spaced at a specified geographic interval. The most common spacing is three arc seconds in both the south-north and west-east directions; with data coverage usually defined in terms of cells that cover one square degree.

DMA-Standard DFAD is a vector formatted product that contains digital feature and cultural data representing point, line, and area attributes. Each digitized feature is coded under a user specified feature identifier and heirarchy, and is then sorted and stored on magnetic tape. The tape is organized into files that represent a corresponding manuscript.

Perspective Plotting Software Modules

Perspective scenes from the Perspective Plotting Software are produced to support a variety of operations. These scenes vary in detail; but requests for them usually specify the area of interest (as denoted by longitude, latitude, and map sheet designation), the observer's location in geographic coordinates, the observer's elevation, the line of sight azimuth, the angle of view, and the locations of prominent terrain locations and features to be annotated. To create a satisfactory scene, the cartographer uses the four program modules of the Perspective Plotting Software after he evaluates and adjusts the user's parameters, the existing digital terrain elevation and feature data, and the map sources corresponding to the digital data (see Figure 2) (Scillian, 1981).

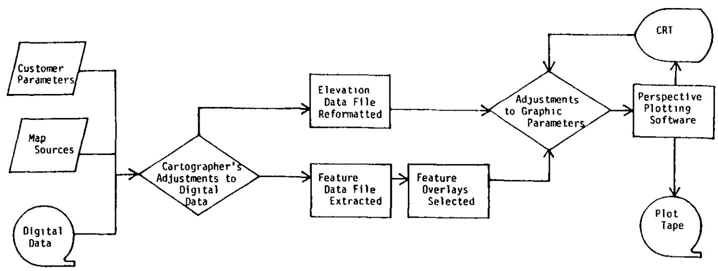

Figure 2. Flow of Perspective Scenes Creation

Both DTED and DFAD require a large amount of storage when directly read into the computer. For example, one DTED cell takes about 2.8 megabytes of disk space if it is directly loaded from magnetic tape. Searching for specified elevations and features is a time-consuming task, unless a strategy is devised to reduce search time. The Perspective Plotting Software, therefore, employs three preprocessing programs: one program to read, compress, and reformat the elevation matrix from magnetic tape to a fast, direct access disk file, and two programs to extract and sort feature data from tape to disk according to the specific needs of the cartographer.

The first adjustment the cartographer makes to the customer's parameters is the choice of the elevation matrix data resolution needed to derive a sufficiently defined fishnet grid to represent the terrain surface. The elevation matrix is processed with the Terrain Data Loader Program from magnetic tape to a random access disk file. This data can be stored at the full resolution of three geographic arc seconds; or to further compact the size of the elevation file, the data can be thinned according to the cartographer's needs.

If the cartographer needs feature data overlays for the perspective scene, he can select a set of DFAD encoded features and build a feature library disk file with the Feature Data Loader Program. The feature library is then accessed by the Feature Data Preparation Program to build specific overlays. All data files can be saved and used indefinitely to generate a variety of scenes.

Most of the cartographer's adjustments to the perspective view enter the production flow when he executes the Perspective Plotting Program. To produce the desired view, the cartographer varies the vertical scale exaggeration, the fishnet grid detail, the declination angle, the angle of view, and the horizon distance. He can also add terrain features, denote points of interest, and mark the distance from the observer to points of interest by spacing with equidistant range lines. Since the software employs a fixed viewing frame, the view can be magnified by varying the viewing angle, thus simulating camera views with various focal lengths. Depending on the size and detail of the scene, the program is executed on a Univac 1100 series computer in batch mode or interactively on a TEKTRONIX Graphics Terminal. With the graphics terminal, the cartographer can quickly manipulate the viewing parameters of the perspective scene before he creates an off-line tape for plotting the finished graphic.

Graphic Product

The graphics produced by the Perspective Plotting Program have four parts: a fishnet elevation drawing and spot feature legend, a general legend, an optional pie-chart orientation diagram, and optional feature overlays. At the present time, precision graphics are plotted on DMAHTC's Calcomp and Xynetics plotting systems from magnetic tape files.

The plotting software produces the fishnet elevation drawing by mathematically projecting a three dimensional surface onto a fixed, two dimensional drawing (see Figure 3a). Selected local points of interest, as defined by geographic or UTM coordinates, are annotated on the drawing and are referenced in a spot feature legend by a user defined three digit code. The spot feature legend also includes information about the heights, distances, and locations of the local points of interest, as well as a determination of whether the points are visible to the viewer. A scene title is placed above the fishnet elevation graphic.

The general legend contains the user's input parameters, the name and resolution of the data base, and a computed approximation of the size of the fishnet grid rectangles used to represent the surface in feet or meters (see Figure 3b).

The optional pie-chart diagram (see Figure 3c) displays the horizontal orientation of the perspective view relative to the

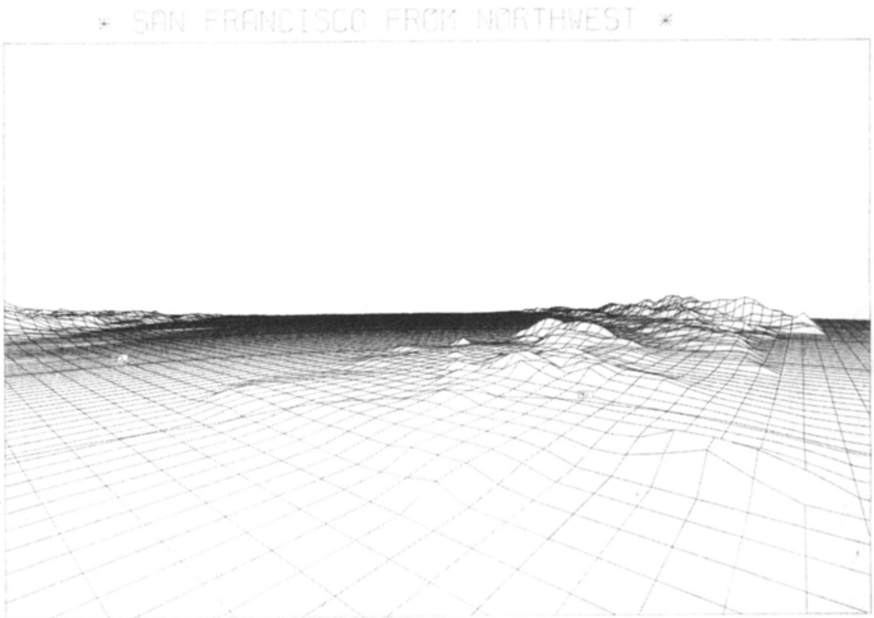

Figure 3a. Fishnet Terrain Graphic

SPOT FEATURE LEGEND

ID	VIS	LAT	LON	ELEV(FT)	COMMENT
APT	N	373730 N	1222230 W	0	AIRPORT
PK1	Y	3748 0 N	1222030 W	243	GOLDEN GATE PARK
AP1	Y	3745 0 N	12210 5 W	0	NAVAL AIR STATION

DATABASE INFORMATION	
NAME	SFRANT
LATITUDE SPACING	6 SECONDS
LONGITUDE SPACING	6 SECONDS
OBSERVER SITE INFORMATION	
LATITUDE	37 50 10 N
LONGITUDE	122 30 30 W
TERRAIN ELEVATION	400 FEET
OBSERVER ELEVATION	2400 FEET
PLOT INFORMATION	
AZIMUTH OF VIEW	140 DEGREES
ANGLE OF DECLINATION	5 DEGREES
HORIZONTAL FIELD OF VIEW	90 DEGREES
RANGE LIMIT	25 MILES
PLOT GRID INCREMENT	18 SECONDS
ELEVATION EXAGGERATION	X 3.0
GRID SIZE, NORTH - SOUTH	1021 FEET
GRID SIZE, EAST - WEST	1443 FEET
RANGE LINE SPACING	5.00 MILES

SYMBOL	CODE	DESCRIPTION
+	261	BRIDGES
+	264	BRIDGES
+	265	BRIDGES
+	267	BRIDGES
⍋	321	STADIUMS
Δ	420	SINGLE FAMILY HOMES
X	231	SHORELINES

Figure 3b. Legend for Perspective Scene

viewer and the grid north represented by the included north arrow. The pie-chart also includes range lines, if the cartographer selects them on the elevation graphic.

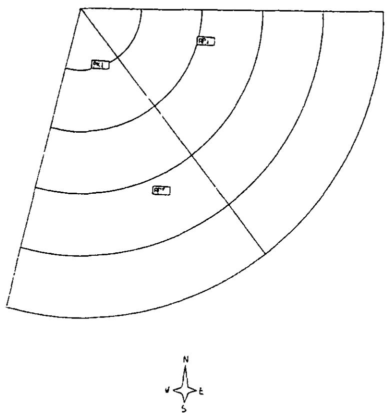

Figure 3c. Pie Chart Diagram

If the cartographer has included feature overlays, up to ten separate overlays can be plotted. The overlays contain point, line, and area data which are currently symbolized with standard CALCOMP alphanumeric and special symbols. Figure 3d shows an example of a feature overlay. The linework of the overlays can be produced in various colors available on the plotters. The linework can also be used in conventional photographic processing to create color separation negatives.

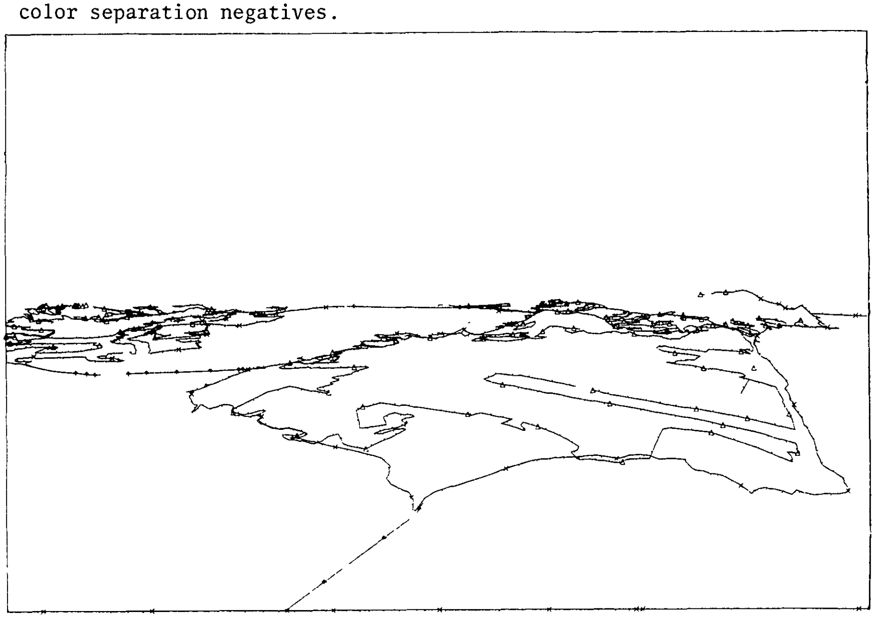

Figure 3d. Feature Overlay

The Perspective Plotting Program

When the Perspective Plotting Program constructs the perspective scene, it first reads the cartographer's viewing parameters and sets up the required geometric relationships. The software then performs the following four processes concurrently: reorganization of the input data relative to the observer's location, terrain data transformation, hidden line analysis, and plotting of feature data overlays (Junkin, 1982) (Wright, 1973).

To assist the hidden line analysis and to speed data access during the data transformations, the terrain data file is reorganized to reference four quadrants around the observer. The quadrants are bounded by divisions of the data base along lines directly south-north and west-east of the observer's location. Based upon the azimuth of the center of the view and the angular range of the view, the software determines which quadrants are visible. Because the software is limited to views less than 180 degree wide, only one, two or three quadrants can be visible to the observer.

The Perspective Plotting Program uses a basic projective transformation to construct a two dimensional drawing (x,y) of a numerically defined, three dimensional terrain model (X,Y.Z). To derive a two dimensional diagram, projection lines, which pass through a fixed frame viewing window, are computed between the observer and points on the object. A perspective scene is constructed on the window by plotting the image that is defined when the intersections of the window plane and the projection rays are computed. For matrix formatted terrain models, the matrix elevations describe the three dimensional object as a set of rectangularly spaced posts. The perspective window image consists of projected pairs of points, representing the tops of the posts, connected by line segments. To insure that hidden terrain is not drawn on the viewing window, the software first transforms the closests pairs of post positions by determining which visible data quadrants are not partially hidden behind neighboring quadrants. Each three dimensional terrain quadrant is scanned from front to back, and the two dimensional graphic is constructed from bottom to top. As the pairs of points are transformed, a clipping function determines whether all or part of the constructed line segment is hidden.

The clipping function used by the program is a procedure that compares a transformed line segment with a special data structure. The structure contains a list of the highest, previous plotted vertical coordinate associated with each horizontal coordinate of the viewing frame. If the vertical coordinate of any part of the line segment is less than the vertical coordinate that corresponds to the same horizontal coordinate in the data structure, the coordinate is assumed to be hidden and it is not plotted. Because the software can divide line segments into visible and invisible parts, a high degree of precision is introduced into the perspective drawing.

The program transforms feature data overlays along with the terrain data. As the clipping function examines the terrain data for hidden line segments, it identifies and saves visible feature segments. The visible features are later retrieved and plotted according to their designated overlay file. Since the cartographer uses preprocessing programs to save only data required to build transformed overlays, required search processes work quickly.

Summary of Current Capability

The efficient, modular approach of the Perspective Plotting Software enables DMAHTC to produce graphics from the computer within minutes. The interactive process also greatly enhances this capability by allowing the cartographer more immediate feedback than the original TOPORAMA process. The software can currently produce plot data for two of DMA's precision plotting devices, and these plots can be used to create photographic overlays.

A LOOK AHEAD

As previously stated, three dimensional views offer an easily visualized representation of terrain. However, potential users have stated that a perspective view would be more useful with accurately placed and better symbolized planimetric features overlaid onto the terrain surface. Planimetry adds more quantitative information to the projection, and it allows the user to quickly relate the three dimensional view to the traditional topographic line map. Perspective symbolization gives the map user a realistic picture (model) of what an area actually looks like when locally viewed. The symbols contribute greatly to his ability to understand the contents of the scene and to plan the activities that prompted his need to view the map area. Figure 1 is an illustration of the kind of enhancements possible.

Among the problem associated with overlaying features on a three dimensional surface are drawing symbols in perspective and determining the location of hidden objects. The previous section reviewed research at ETL/ECAC that resulted in an approach to the perspective projection which efficiently solves the hidden line problem. ETL and DMA expect future developmental work to solve the problem of producing computer generated symbolization in perspective including lines of communcation, such as roads and streams, and also point symbols, such as buildings and towers.

Additional future research will also expand upon methods of analytical hill shading. The approach will be based upon initial work performed by Yoeli (1967). This work employs mathmatical techniques to produce shaded relief depicting terrain surfaces in three dimensions. Since these techniques combine the surface geometry of the terrain and its photometric properties, the resulting scenes should more closely approximate "real" views than those of other techniques based solely on the geometry of projected lines (Taylor, 1981).

The advent of sophisticated output devices has made it practical to maximize the use of labor saving automation to produce hill shading. Additionally, the devices eliminate the traditional artistic bias that is inevitably introduced by the cartographer using conventional hill shading techniques, allowing for rapid production of uniform three dimensional shaded relief maps.

CONCLUSION

Given the assumption that digital cartographic data bases exist, and their content will improve in the future, automation should speed up the ability to produce detailed perspective scenes. We believe that graphics will prove highly useful in aiding the interpretation of the conventional topographic map. DMA and ETL have developed a basic software to derive three dimensional scenes from both elevation and planimetric data bases. By developing and applying further symbolization techniques that are useful when presenting perspective graphics, DMA and ETL expect to help remedy basic problems with the map reading process.

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Raster-Vector Conversion Methods for Automated Cartography With Applications in Polygon Maps and Feature Analysis

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ABSTRACT

In this paper, we discussed the concept of data base conversions between raster format and vector format. With a series of cartographic experiments, we have demonstrated that polygon maps can be generated from raster data without losing the visual quality provided that the editing process is performed to remove the grid cell effect. The methodologies discussed in this paper can therefore serve as a model for using raster data for automated cartography.

INTRODUCTION

Polygon maps constructed by plotters are usually based on vectorized data sets, each constituting a distinctive, labeled region enclosed by a series of line segments. With areal density or typed symbols, these maps are generally called choropleth maps in the cartographic literature. Using the most popular mapping program SYMAP, as an example, the array of (X,Y) coordinates used to bound a region, called A-Conformal Line in that program, is in fact a vectorized data set. The quantitative or qualitative measure for that region, called E-Values, is the basis for generating the statistical surface with the choropleth method.

Instead of using only the edge information, the cartographer can employ a data set that covers the entire study area with a matrix format for mapping purposes. Such data set is called raster data; digitized imagery is one of the most popular forms.

To use raster data for production of maps with line plotters, the raster data have to be processed, and structured in such a way that they contain only two types of information: edges and the interior, corresponding to the A-Conformal Line and E-Values of SYMAP, respectively.

This paper discusses general methodologies for producing edge and interior information using imagery data as examples, and illustrates the techniques for the generation of polygon maps based on raster data with a series of computer maps.

PROCESSING OF RASTER DATA FOR CARTOGRAPHIC APPLICATION

For a given study area, raster data characterizing the statistical surface can be of either univariate or multivariate nature. Using image data for example, digitized black and white imagery can be considered as univariate; whereas multispectral imagery is multivariate. This classification is based on whether merging of two or more data files is needed to create a single file for mapping purposes. Methods for processing these two types of data are discussed below.

Processing of Single-Channel Data for Raster-Vector Data Base Conversion

The purpose of data processing is to generate distinctive regions and produce edge and interior information for each region. In the context of image data analysis, methodologies for such purposes belong to the general concept of supervised classification and scene segmentation or unsupervised classification.

Supervised classification utilizes calibration samples, called training sets in image processing literature, to classify the entire study area according to given categories plus a rejected class. The techniques for performing supervised classification have been discussed by many researchers and can be obtained from standard textbooks in remote sensing such as these by Sabins (1978) and Hall (1979). A simplified version was given by Hsu (1979).

To classify features or terrain types with one channel data, multiple measures for a given point are generally required to obtain a high rate of correct classification. This is because a single measure for the raster data usually does not give enough information for discrimination purposes. To increase the number of measures, spatial information is generally used. This type of approach is one of the forms of texture analysis; a cartographic approach was given by Hsu (1978).

Provided that there exists enough information in the spectral and spatial domains of the raster data, the training sets are properly selected and analyzed, and finally the classification logic is capable of handling the distributional characteristics of the data, a good classification map can be obtained with appropriate data processing techniques.

The final classification map is in fact, composed of two basic cartographic elements: edges enclosing the classified regions, and the interiors representing the characteristics of the regions. In terms of the SYMAP language, edges are A-Conformal Line, whereas interiors are E-Values. Therefore, when these edges and the information of the interior of each region are extracted and stored in a different data file from the classified map, we have in fact converted the raster data into vectorized data, which can be used by line plotters to generate polygon maps.

In addition to the above-discussed supervised classification method, a family of image processing techniques based on the concept of segmentation can be utilized to generate distinctive regions. In the remote sensing literature, it is generally called unsupervised classification method.

Scene segmentation can be approached from either edge detection, or region growing point of view. The former technique discovers the boundaries of distinctive region using local statistics from adjacent points, whereas the latter delineates distinctive areas by clustering "homogeneous" data points until the growing process touches the edges where another region begins spatially. A more detailed discussion on these topics can be obtained from Hall (1979).

Similar to the classification map generated by a supervised method, the segmented scene can be coded in terms of the edge and interior information using a vector format. Thus a conversion from raster data to vector data can also be achieved based on scene segmentation techniques.

Processing of Multi-Channel Data for Raster-Vector Data Base Conversion

Similar to single-channel data, multi-channel data in raster format like LANDSAT imagery which has four spectral bands, can be processed by means of both supervised and unsupervised classification methods for mapping purposes.

The methodologies for using multi-channel data to classify a scene are essentially the same as those used in the processing of a single-channel data except that the number of features variables increases by a factor of equal to or larger than the number of channels. For instance, if there are three variables (one tone plus two texture measures) from each band, the number of variables available for analysis in a 4-channel system is at least twelve (12) because additional variables can be derived from ratio bands between any of two channels.

To segment scenes with multi-channel data, certain types of single-band data must be generated by merging these multi-bands. Above-mentioned ratioing technique is one of the commonly-used methods for merging two frames into one.

Another useful technique is the principal component analysis. As it is well-known in the multivariate statistical analysis literature, the number of components is equal to the number of variables; however, only the first few components would provide meaningful information. Using the LANDSAT MSS data for example, usually the first and the second components provide meaningful information.

For segmentation analysis, the component scores map is used as the base representing a combination of the multiple-band data. The meaning of the component has to be interpreted from the relationship between the component and the original variables. Using the LANDSAT data as an example again, the first component usually represents a linear combination of four bands, which is equivalent to panchromatic imagery.

Once the classification or segmentation maps are generated using the above discussed methods with multi-variable data, the same edge and interior extraction algorithm for the analysis of a single-band data can be used to generate vectorized data for plotting polygon maps. The following sections discuss the methods for generating polygon maps using a series of experiments to illustrate the concept of raster-vector data conversion methods as discussed.

EXPERIMENTATION ON RASTER -VECTOR DATA BASE CONVERSION

The Original Data Base

Our experiments begin with a polygon map constructed by a line plotter showing different soil regions as in Figure 1. Note that each region is composed of a series of line segments enclosing that region. Some line segments are shared by two adjacent regions. This map is therefore based upon vectorized data.

To show that raster data can be utilized to generate polygon maps via a data base conversion method, Figure 1 was first converted to Figure 2 showing the interior information instead of the edge information, and then to Figure 3 conveying the same idea but with a raster data set composed of (65 x 58) data points.

From Raster Data Back to Vector Data

Figure 4 was generated from Figure 3 to depict the edges and the interior of each region using the following scheme (Figure 4a) and algorithm. To extract the edges and the interior simultaneously, we need to identify three types of boundaries:

(1) exterior boundary separating two regions like that between region 5 and region 6 of Figure 4a;

(2) interior boundary identifying the inner region like region 6 using (-1 sign) as the region ID Code;

(3) common boundary between grid cells of the inner region.

The purpose of using these boundaries is to create the necessary edge information (4 edges) for each control point or raster data point so that the exterior boundary can be determined by identifying and subsequently eliminating the interior and the common boundaries that identify a given region.

For example, in Figure 4b IXY (i,j) identifies the center point of a given grid; and (i,j-1), (i+ 1,j), (i,j+1) and (i-1,j) are the ID codes for the four edges of the control point. In addition, (i+1,j), the second edge, is (-1) according to the information given from the adjacent control points, thus it is the interior boundary. Using the same principle, all of the exterior boundaries can be determined, displayed and stored.

The data structure of the stored data is given in Figure 4c. Data Set 1 (Column 1 of Figure 4c) is composed of all the distinctive regions. Each region is subdivided into three sections:

(1) left-hand side is the mother region;

(2) right-hand side indicates adjacent regions;

(3) center part are the (X,Y) coordinates for all of the boundary points; and the boundary points are further identified by the condition whether they belong to one or two adjacent regions. For instance, A are boundaries points without adjacent regions, whereas B, C and D are points shared by region 1 (mother region) and adjacent regions 6, 3 and 2 respectively. Such information is extracted and given in Data Set 2 (Column 2 of Figure 4c). Data set 3 (Column 3 of Figure 4c) identifies line segments that are not shared by two or more adjacent regions.

Figure 5 is constructed from Data Set 1 of Figure 4c, indicating that boundaries separating adjacent regions are plotted (repeated) twice because of the raw data of the boundary points are used.

To eliminate such double-plotting of boundaries, and to be able to extract individual regions, the data structure composed of Data Set 2 and Data Set 3 has to be utilized based on the fact that:

(1) no overlapping line segments exist in Data Set 2;

(2) boundaries either belonging to a single region or shared by two regions are identified in Data Set 3;

(3) data points shared by two or more line segments are identified.

Refinement of the Polygon Map

As can be noted on Figure 5, the edges between adjacent regions are darker than the border lines because they are drawn twice by the plotters based on the fact that these line segments are used by two adjacent regions by the plotter.

The polygon map in Figure 5 can be refined first by removing the second plotting on the border line segments as shown in Figure 6 where line weight is even throughout the entire map.

Since Figure 6 is based on raster data, the grid-cell effect exists between nodes of line segments as compared to the original, vector-based map of Figure 1. To produce a visually-pleasing map, Figure 6 was edited by "chiseling" corners produced by grid cells according to the method illustrated in Figure 6a. To eliminate corner points, every 3-point series is examined to determine the existence of corner points. Intermediate points are eliminated by examining the slopes between every two adjacent line segments (each segment is defined by two points). If slopes are equal the center point is eliminated, and vice versa. The final polygon map is shown in Figure 7, and it is almost identical to Figure 1, the original map based on vector data. This proves that our methodologies for raster-vector data base conversion are very effective.

APPLICATIONS IN FEATURE ANALYSIS

In image processing, polygons determined by distinctive edges usually represent unique features, such as soil, vegetation, cultivated fields, etc. Once the edges of these features are determined, the texture and tone information of these features can be extracted from the pixels in the interior enclosed by the polygons.

For feature analysis, we in fact utilize the raster data and the vectorized data simultaneously; the former is the interior and the latter is the edge. This model's analysis is applicable to multi-channel and multi-temporal image data sets.

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Figure 1: The Original Soil Region Map with Vector Data

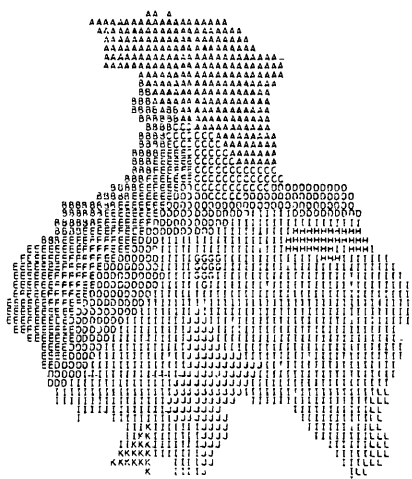


Figure 2: A Raster Data Map of Figure 1

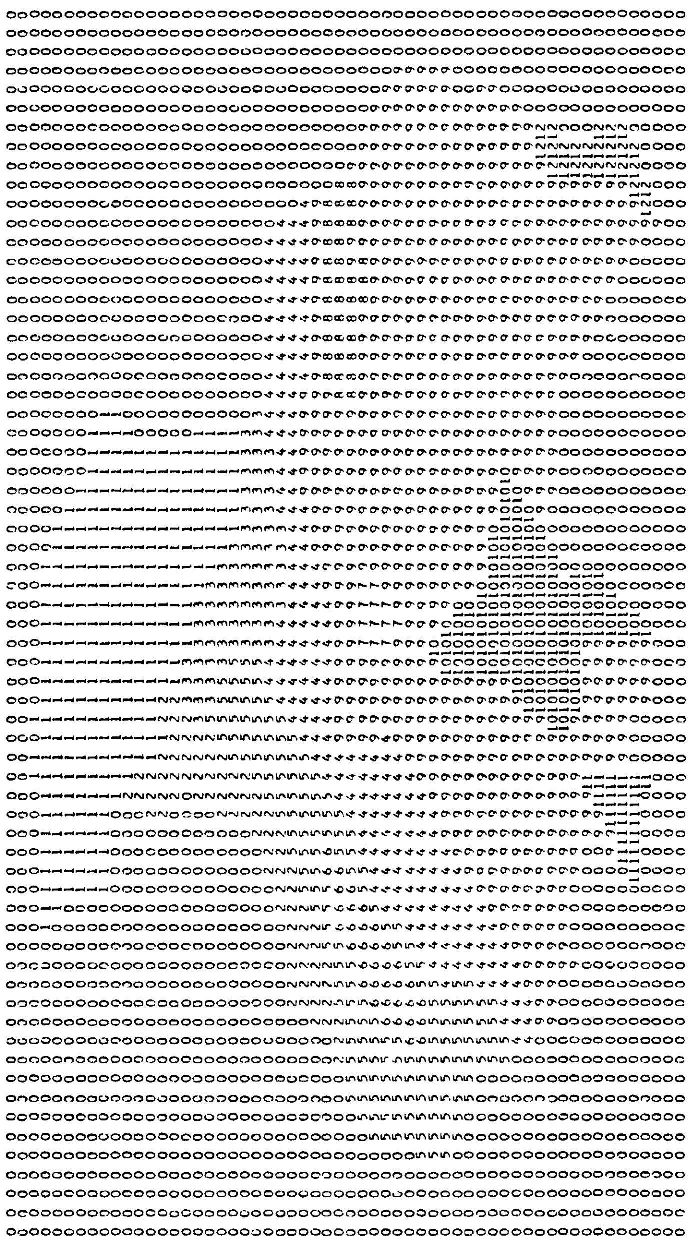


Figure 3: Full Matrix Map of Figure 1

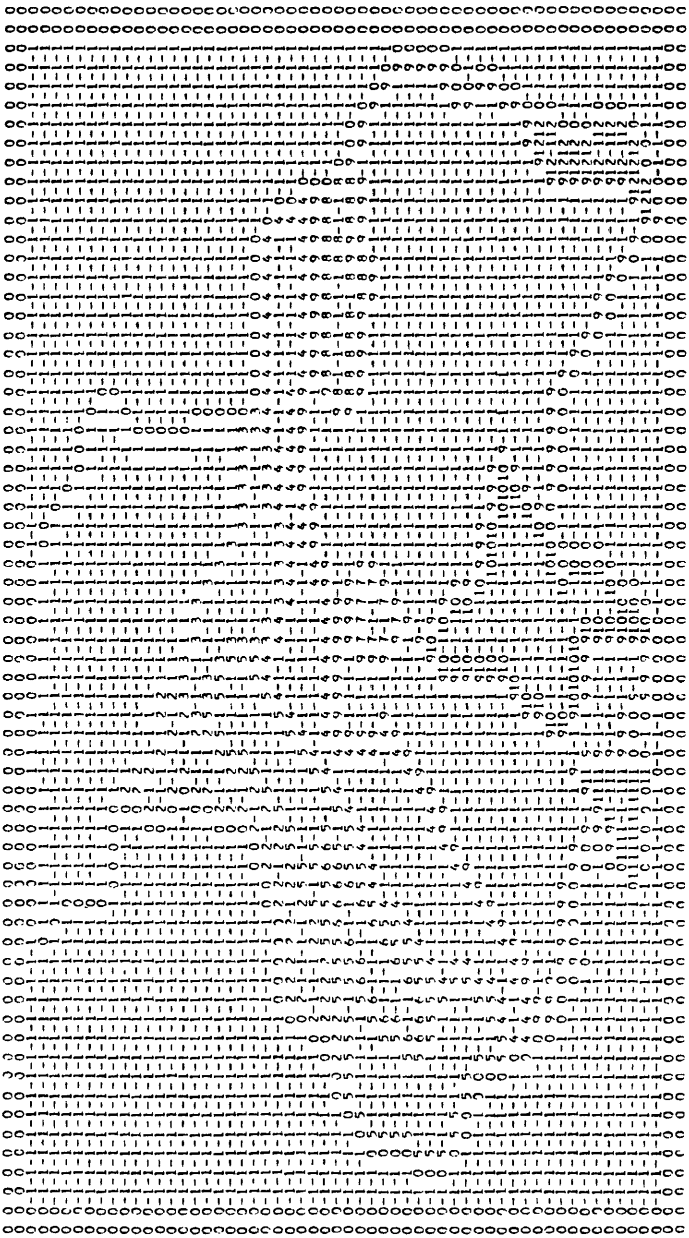


Figure 4: Edge and Interior Map of Figure 3

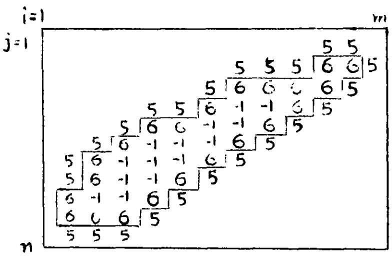


Figure 4a: Three types of boundaries identified

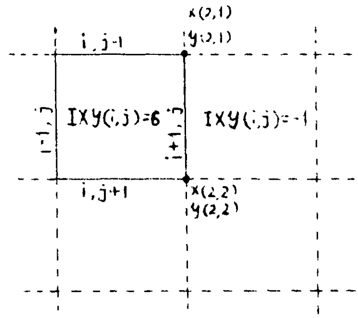
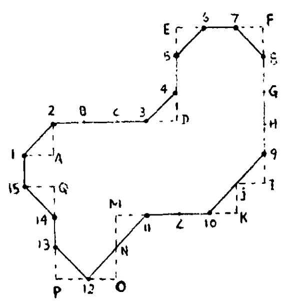


Figure 4b: The ID codes for the center point and four edges of a given grid



Corner points eliminated:
A,D,E,F,I,K,M,O,P,Q

Intermediate points eliminated:
B,C,G,H,J,L,N

Points stored:
1,2,3,4,5,6,7,8,9,10,
11,12,13,14,15

Figure 6a: The points edited and stored

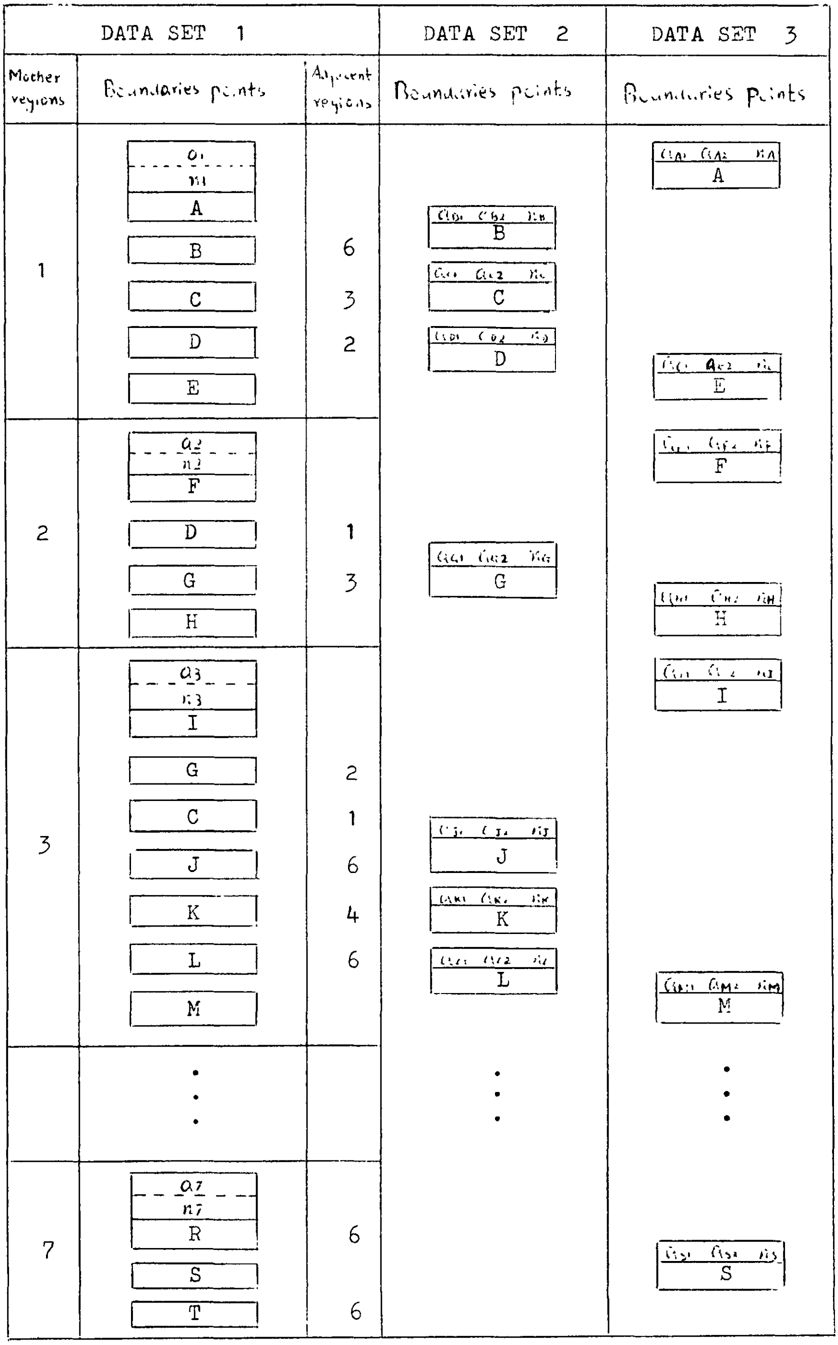


Figure 4c: The Data Structure

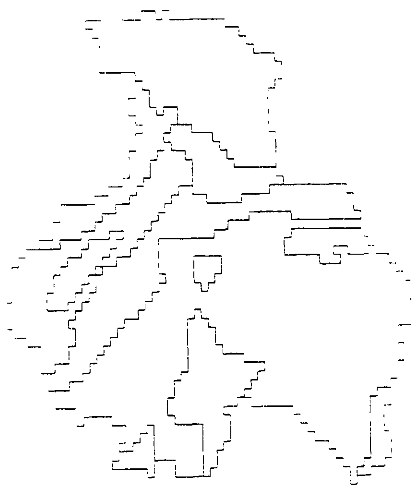


Figure 5. Raw Vector-Plotter Map from Figure 4

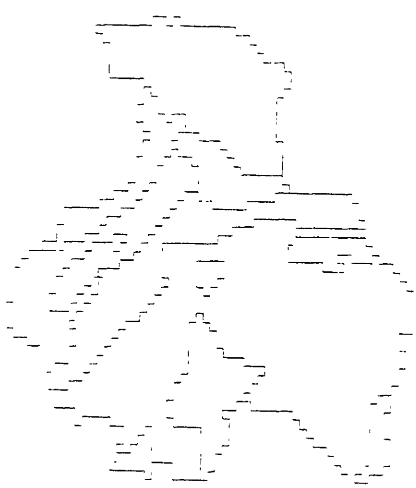


Figure 6 Refined Vector-Plotter Map from Figure 5

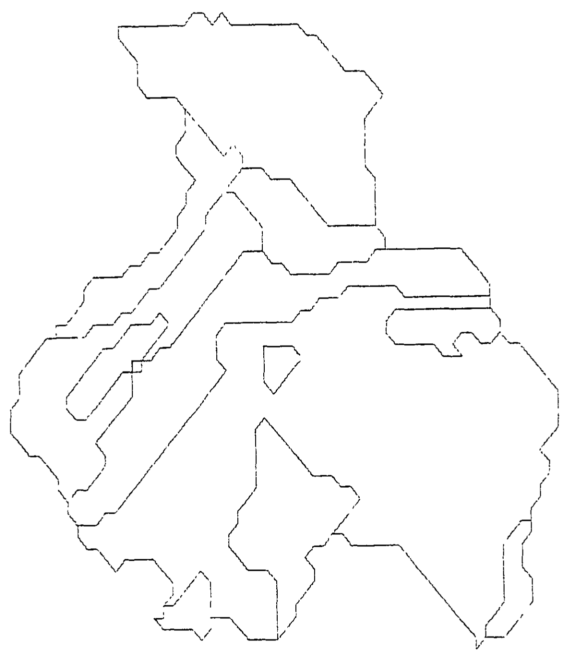


Figure 7: The Final, Edited Map
from Figure 6

LANDSAT CAPABILITY ASSESSMENT USING GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

With the recent availability of large accumulations of detailed cartographic and other spatial data, various groups including government planners, engineering consultants, and resource managers are seeking computerized methods to store and manipulate the mapped data bases. This need has led to the development of computer-based geographic information systems (GIS) which replace the traditional overlay approach in land capability analysis (McHarg, 1969). More recent GIS software features a variety of parameter modeling procedures, color CRT display interactive capability, proximity modeling, and the ability to enter remotely-sensed data (e.g., satellite, aircraft, etc.) and input parameters.

OVERVIEW

For several years, the intense need for more effective and sophisticated methods of managing resources and assessing environmental impacts has been apparent. A fundamental requirement for effective resource management is information. To be of maximum use, the information must be accurate, timely, comprehensive, readily retrievable, and subject to a large and flexible array of analytic and interactive display approaches.

Fortunately, in the last decade, rapid advances have been made in both remote sensing and geographic information system technologies. The tools and concepts now exist to develop the required computer software and data bases.

One problem, which has always limited the application of these computer-based systems, is the high cost of establishing the digital data base files. A breakthrough in this cost is the application of techniques which permit the generation of digital land cover files from data interpreted from satellite (Landsat), aerial photography, and conventional map sources. Utilizing advanced data restoration techniques, the Landsat data can be resampled to a 50 x 50 meter cell size. Computer-assisted interpretation transforms Landsat measurements into land cover codes. This interpretation provides a fast, low-cost source for non-urban cover types, e.g., cropland, grassland, barren land, forest, nonforested wetlands, water, etc. Land use categories to be merged with the Landsat data are delineated on maps and aerial photography and digitized into the same map projection and scale as the interpreted Landsat data. The Landsat and the manually interpreted/digitized files are then merged in the computer and used as the source for map and data products.

Products resulting from this multisource procedure include: color maps and map overlays, land cover tabulations, and digital data files.

GEOGRAPHIC INFORMATION SYSTEM REQUIREMENTS

A computer-based geographic information system is basically a geo-referenced system for storing, retrieving, and manipulating mapped data (Campbell, 1981). In contrast to a conventional data base management system, the parameter data of a GIS must be related to a place or location identifier.

There are three major factors to be considered in the design of a computerized geographic information system. The first of these factors is the technique to generate and register digital files of geographic areas and resource management attributes such as topography, forest cover, land use, water type, etc. The second factor is the development of a data base management system which is used to catalog, store, and retrieve the digital file containing the resource information. The third factor is the software to be used to manipulate the data base and extract the required resources management information, and the hardware to display interim and final results. These three factors (Data Base Capture, Data Base Management, and Data Base Manipulation and Display) comprise the geographic information system.

Data Base Capture

There are many types of data to be entered into a geographic information system. Graphical information is usually presented to the system as a map. The maps can be in any number of scales and projection and will contain areal information in the form of polygons (timber type, land use, political boundaries, etc.), lines (roads, streams, etc.), and points (well known locations, topographic high or low points, bench marks, etc.). Other types of data to be entered include cellular or raster data (Landsat, digitally scanned data, etc.) and tabular data (statistics, etc.).

The most common method for the entry of graphical information is through the use of a coordinate digitizing table. Given the nature of maps used in resource management projects, the majority of the information will be digitized as polygons. Data manipulation is more easily performed with cellular data. Nevertheless, there are large advantages to storing the area data as polygons. The more advanced software packages will utilize the flexibility and compactness of polygon storage while providing the simplicity of data manipulation afforded by cellular modeling techniques. Tabular data can be viewed as single point polygonal data and can be processed using the same software as that required to manipulate the graphical data. Processed Landsat data is, of course, already in a cellular format and would be stored in that form. The software should allow the registration of these various data types, perform a polygon to raster conversion, accept geodetic coordinates (latitude, longitude), and produce a cellular data file in the specified projection and cell size. A typical data base might include data resampled to a 50 x 50 meter cell (compatible with the Landsat resolution) in a UTM projection.

Data Base Management

As data is captured, it must be indexed and catalogued for later retrieval. One of the most important decisions to be made in the evolution of an information management system is the structure and organization of the file. The design of the file structure and organization of the file. The design of the file structure is a function of the type of information desired from the data base. The file structure must be designed to permit simultaneous sorts by several attributes. Typical retrieval requirements are sorts:

- By land use category of type,
- By area (political boundaries, watersheds, etc.),
- By time period (year, month, etc.), and
- By source (satellite, aerial photography, etc.).

The structure can be hierarchial (tree structure) or matrix. For a particular resources management project, the data bases may be queried to collect the data required for manipulation.

Date Manipulation

In order to have a GIS accommodate multiple users and applications, the system design should be flexible enough to accept a variety of data base parameters capable of being analyzed with a common operating procedure. Optimally the system should provide the following functions:

1. Retrieve one or more data elements from a parameter file;
2. Transform or manipulate the values in the data element retrieved;
3. Transform, manipulate, or combine the data elements retrieved;
4. Store the new data element created by the analysis in the data file;
5. Search, identify, and route a variety of different data items and score these values with assigned

weighted values (e.g., search for optimal highway routing) - the capability is highly desirable and complex;
6. Perform statistical analyses, such as multivariate regression, correlations, etc.;
7. Measure area, distance, and compare these data;
8. Overlay parameter files (e.g., census tract data with land use data);
9. Model and simulate (i.e., develop scenarios), generally in map form, to predict a future event - this is perhaps the forte of a GIS.

TYPICAL APPLICATIONS

There are several important areas where geographic information systems can aid land use planners:

1. Master plan or long-range planning;
2. Determination on the extension of utilities and public sewer/water service;
3. Siting problems, e.g., an industrial park;
4. Environmental impact assessments.

Examples of the above application areas are presented below. Data bases have been developed for Washtenaw County, Michigan and Scio Township, which is a township within Washtenaw County. The county data base contains 10 parameters while the township data base contains 25 parameters, coded on a 100 x 100 meter cell size. Thus each cell represents a surface area of 1 hectare or approximately 2.5 acres.

Many local governments, as well as private companies, develop long-range plans (which are sometimes referrered to as Master Plans) for the comprehensive planning of their respective activities. Such plans should reflect not only a consensus of the community, i.e., nontechnical factors, but also the capability of the land to support the planned use(s). As illustrated by Figure 1, only areas suitable for residential development are shown by the gray-tone pattern (lighter shades related to higher suitability). The suitability map was produced by analyzing five spatial parameters including township zoning, septic tank limitations, water well production, depth to water table, and existing land use. Moreover, the overlay of a parameter representing proposed 1990 public water mains allows the township planners to simulate development and thereby determine if the extension of the public utilities is justified.

Application two, illustrated by Figure 2, shows the areas suitable for industrial development in Washtenaw County. Five parameters were employed in the industrial development model including county land use, and proximity to expressway interchanges. The proximity parameter is an especially important capability in the GIS as it allows the planner to incorporate a gravity or distance-decay function. In addition, this application features an existing land use parameter which was developed from digitizing a map prepared from aerial photography interpretation. Landsat and other

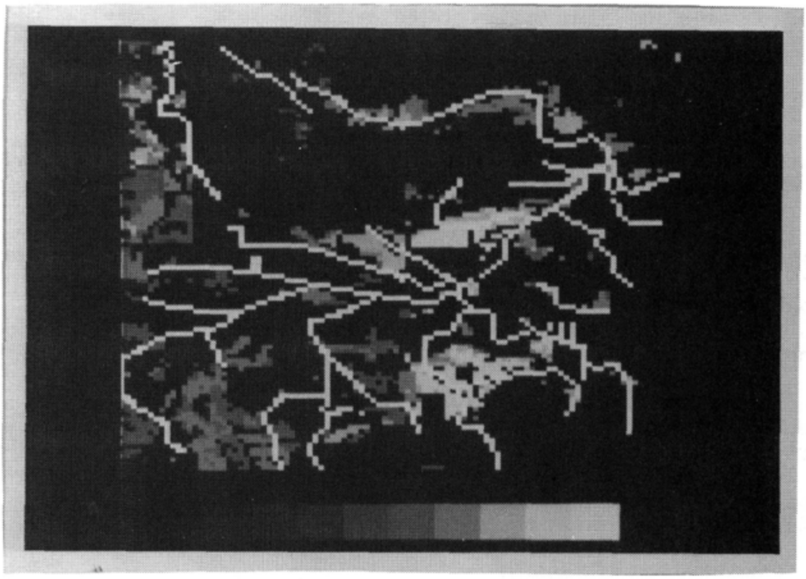

Figure 1. Suitability of Land in Scio Township for Rural Residential Development, with Overlay of Proposed 1990 Water Mains.

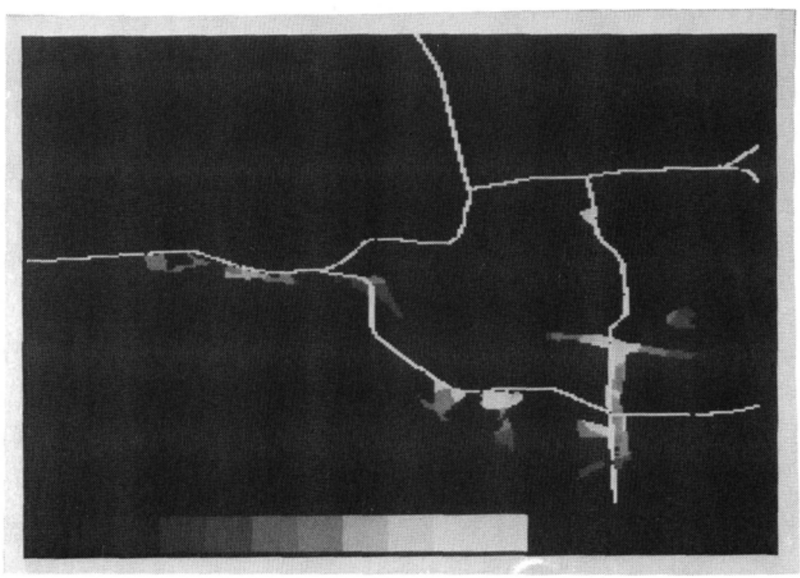

Figure 2. Suitability of Land in Washtenaw County for Industrial Development, with Major Highways Overlaid for Geographic Reference.

remote sensing platforms could also provide existing land use data.

Application three illustrates the utilization of a GIS in performing environmental impact assessments (Figure 3). Six parameters were employed in the suitability model including depth to water table, wetland type, forest type, water well production, soil type (agricultural potential), and existing recreational land use. To simulate the effect of selected environmental regulations, the wetland type and soil type parameters were assigned a weight of 2.0 whereas the remaining parameters were assigned weights of 1.0. The capability to assign weights to parameters is an important GIS feature especially when multiple suitability maps are compared.

Taking multiple suitability maps a step further, the system should be capable of generating a composite suitability map utilizing several different suitability models which pertain to a single application. For example, with regard to a hypothetical hazardous waste landfill siting model in Scio Township, three suitability maps were prepared which represent distinct planning postures: prodevelopment, neutral, and environmental/conservative. The three suitability maps were then incorporated as derived parameters in a new data base file. The resultant suitability map (Figure 4) highlights the commonality between the three alternatives. Geographic areas with high scores are cells which received high suitability values from all three simulated postures. Moreover, composite maps may facilitate concensus among planners, and can point to areas where site-specific data must be collected.

The degree to which the overall and composite nature of the future landscape is affected by alternate value systems represents the sensitivity of the land resource. By assuming a set of alternate value systems covering the spectrum of public opinion, the land use planner can generate a set of alternate land use maps, and thus assess himself of said sensitivity prior to the public hearing process. Furthermore, by submitting such a set of land use scenarios to the public forum, the land use planner can make the public hearing process a more meaningfull one from the outset.

FUTURE POTENTIAL

Recent advances in both hardware and software have opened up an exciting new area for the application of GIS technology - land assessment and resource management for areas of the world where current cartographic information does not exist or is inadequate.

The hardware advance providing this capability was the development of the TRANSIT series of satellites, allowing accurate positioning of marine vessels. In 1967, the Navy made the system available to nonmilitary users. As of 1975, six satellites were in operation in circular polar orbits at a nominal altitude of 600 nautical miles and with a nominal

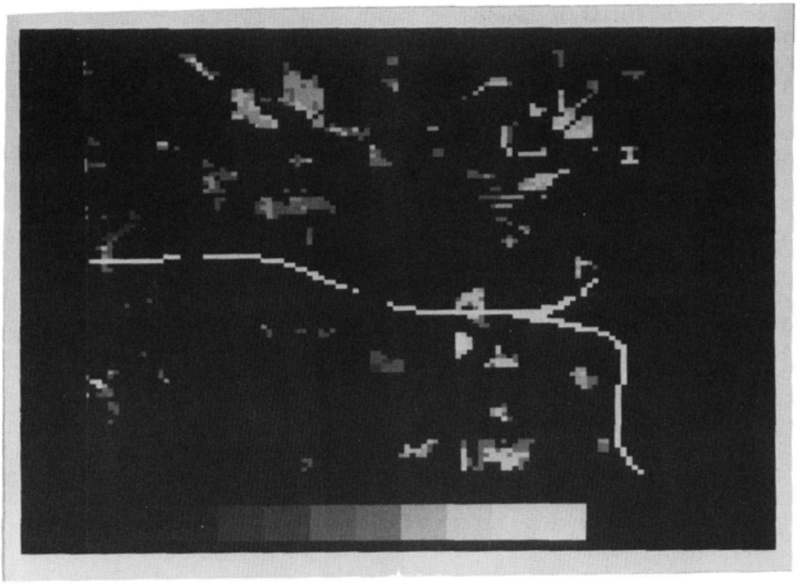

Figure 3. Suitability Map of Scio Township Showing Environmentally-Sensitive Areas.

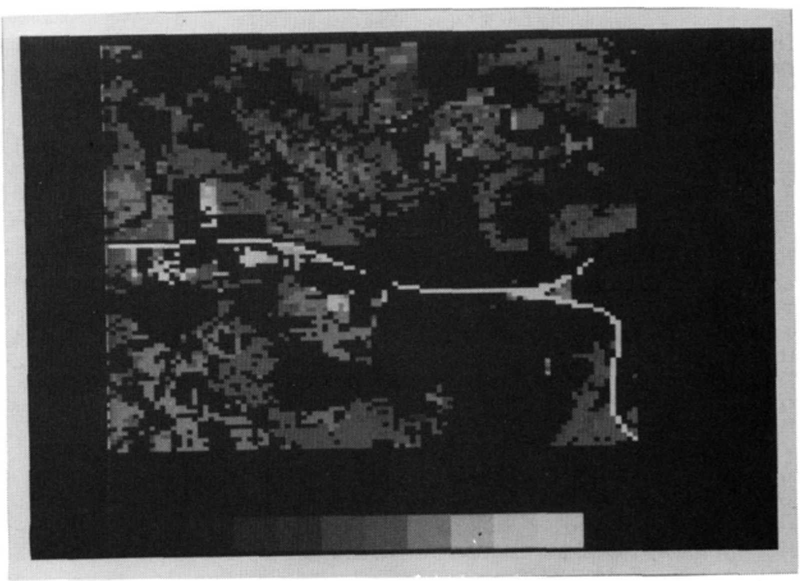

Figure 4. Composite Suitability May Showing Areas in Scio Township Suitable for Hazardous Waste Landfill.

period of 107 minutes. The number of usable passes per day range from 8 to 12 near the equator to 40 to 50 in arctic regions. To make use of the system, an observer needs a small antenna, a lightweight receiver, and a tape recorder to store the observations. Many current systems also include a microcomputer to process the data on site. By positioning these receivers at sites which are photoidentifiable in satellite (Landsat) imagery, the control points can be precisely located in latitude, longitude, and elevation. These precisely located points can then be used to geometrically correct the satellite data.

Recent software techniques have been developed for highly accurate geometric correction of Landsat satellite data. The software uses high order polynominals to map Landsat data into the desired projection, correcting spacecraft and sensor distortions in the process. The accuracy of the correction is limited by the resolution of the Landsat data and the precision with which the image and map control points are located. The desire to produce the geometrically correct imagery with as few control points as possible led to the derivation of a "model" for the Landsat spacecraft and scanner.

The "model" rigidly defines the spacecraft and sensor with a least squares fit between predicted and observed control points refining the spacecraft roll, pitch, yaw, roll rates, pitch rates, roll accelerations, and pitch acceleration. In principle, five control points can completely compensate for any attitude maneuvers performed by the satellite during the collection of the data frame (scene). In practice, 6 to 10 points are normally collected to: 1. reduce the effects and permit detection of a "bad" point and 2. permit averaging to achieve subpixel accuracy in image control point location.

The state of the art for geometric correction and digital mosaicking of Landsat data has reached a level permitting use of such data for small to medium scale mapping of poorly mapped areas. Most Landsat scenes can be geometrically corrected to national map accuracy standards at scales of 1:200,000 or smaller. Current development efforts indicate that the ultimate geometric accuracy of the Landsat MSS scanner could be as good as 25 meters RMS, meeting national map accuracy standards for 1:50,000 scale maps. The Landsat D Thematic Mapper data should be able to easily achieve this accuracy level when the appropriate correction software is developed.

The consequence for GIS technology from this ability to generate planimetric maps utilizing Landsat data is the capability to provide land resource managers with a tool to assess and control future resource utilization in areas where no viable alternative exists. The Landsat derived map becomes the base map unto which the manually interpreted data is transferred. In addition, computer-assisted land cover classification of the Landsat data may be merged with the manually interpreted data in the GIS data base.

It should be noted that the resolution of the Landsat data (50 meters) and the normal scale of the derived maps

(1:250,000) are commensurate with their utilization in areas of poor and/or nonexistent maps.

The new capability means that third world or underdeveloped countries may generate a set of maps conforming to national map standards, produce digital data bases corresponding to the map format, and produce land assessment and resource management decisions which may be referenced directly to the national map series. This ability to achieve GIS technology transfer to nations which are very much in need of the technology for a relatively low cost in a short time-frame is a most exciting aspect of the GIS picture.

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McHarg, I.L., 1969. Design With Nature. Garden City, New York: Doubleday Publishing.

TVA'S GEOGRAPHIC INFORMATION SYSTEM: AN INTEGRATED RESOURCE DATA BASE TO AID ENVIRONMENTAL ASSESSMENT AND RESOURCE MANAGEMENT

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ABSTRACT

The Tennessee Valley Authority (TVA) has implemented a computerized Geographic Information System (GIS) to aid a wide range of environmental assessment and resource management activities. These activities vary in scope from region-wide to site-specific considerations. A major area of application is the administration of reservoir land. There are 23 multipurpose reservoirs in the 7-State TVA system with a combined total of 300,000 acres of land, 660,000 acres of water surface, and 10,000 miles of shoreline. These land and water resources are managed for multiple uses such as forestry, wildlife, fisheries, recreation, and navigation. In addition, TVA annually receives more than 1,500 external requests for the use of reservoir land for a diversity of activities from commercial and industrial development to private boat docks. This paper describes how the data storage, selective retrieval, analysis, and display capabilities of the GIS are being used to aid development of overall reservoir land use plans, formulation of detailed land management prescriptions, and assessment of environmental impacts related to requests for the sale, transfer, or other use of reservoir land.

INTRODUCTION

TVA is a regional resource development agency. In 1933 TVA was envisioned by President Franklin D. Roosevelt as an agency to be "charged with the broadest duty of planning for the proper use, conservation, and development of the natural resources of the Tennessee River drainage basin and its adjoining territory for the general social and economic welfare of the nation." It was a novel approach to the organization of Federal programs: a single Federal agency responsible for encouraging the unified development of all resources in a specific region of the Nation, headquartered in that region, and directly responsive to the needs of its citizens. In pursuit of this goal TVA undertook a broad range of resource development activities, chief among which was the multipurpose development of its reservoir system for flood control, navigation, and electric power production.

A significant base of land was acquired by TVA in conjunction with the development of its reservoir system. The system now spans seven States and includes 23 multipurpose reservoirs with more than 10,000 miles of shoreline and about 300,000 acres of public land.

Consistent with its regional mission, TVA has continuously used its reservoir shorelands to meet a variety of needs in the Tennessee Valley. Because these shorelands include many high-quality sites for various uses and control access to the inexpensive transportation offered by the Tennessee River system, they have traditionally been a catalyst for the development of the region. They are used for a wide variety of TVA activities, ranging from nuclear power plants to recreation sites, forestry, and wildlife management. In addition, they are made available for many other public and private uses, including industrial development, agriculture, parks, and commercial recreation development. To manage effectively the growing demand for development on these lands, TVA has initiated a formal planning process intended to balance competing demands for public and private uses, environmental considerations, and local and regional values.

This planning process depends upon an accurate inventory of the resources existing on the land base and an extremely diverse set of evaluations regarding their suitability for various types of development. To help TVA planners manage and interpret the tremendous volumes of basic resource data necessary for this process, TVA acquired and implemented a computer-based geographic information system (GIS) in 1981. The GIS was purchased from Intergraph Corporation after an extensive evaluation of the ability of available systems to meet TVA's diverse needs. This paper describes TVA's experience in using this system to support land use planning and administration of its reservoir properties. Specifically discussed are the technical problems and the payoffs of this use of geographic information systems.

RESERVOIR LAND MANAGEMENT APPLICATIONS

The data storage, selective retrieval, analysis, and display capabilities of the GIS are used to support a variety of TVA reservoir land management activities. These include (1) resource inventory; (2) development of overall reservoir land use plans; (3) formulation of detailed land management prescriptions; and (4) assessment of environmental impacts related to requests for the sale, transfer, or other use of TVA reservoir land. These applications will be described in detail through the use of a case study.

Guntersville Reservoir, the second largest reservoir in terms of water surface area in the TVA system, will be used as the case study. It is a multipurpose reservoir operated for navigation, flood control, power production, recreation, and other uses. The reservoir is located in northeastern Alabama with a small portion extending into Tennessee. It includes 67,900 acres of water surface, 950 miles of shoreline, and 36,000 acres of TVA-owned land.

Reservoir Inventory

An integrated digital data base consisting of both mapped and alphanumeric attribute data linked internally within the GIS was developed for Guntersville Reservoir. The data base covers the reservoir, TVA-owned land, and a zone extending approximately 1 mile behind TVA-owned land.

Two kinds of mapped data were collected: (1) resource and (2) capability data. Resource data identify the nature and extent of existing landrights, physical features, biological resources, and cultural resources in the reservoir area. Twenty-six data types were integrated into a common geographically referenced data base (Table 1). These data were stored in the GIS as point, line, and area (polygon) features. Most of these data were collected by TVA resource specialists and then entered into the GIS. However, some resource data such as erosion hazard and prime farmland were derived using the data manipulation capabilities of the system.

Capability data, indicating the relative ability of the land to support various uses, were derived by analyzing combinations of selected resource data. Seven categories of capability data were developed by TVA staff using a variety of manual and computer-assisted methods and entered into the GIS (Table 1). This technique was used because these analyses required consideration of transportation, demand, labor, market, or other factors that extended beyond the 1-mile zone behind TVA-owned land.

An extensive alphanumeric attribute data base was developed and linked within the GIS to the mapped data. Attributes are textual and numerical data that describe the characteristics of mapped features. For example, attributes stored for each existing recreation area included: (1) name of the recreation area (e.g., Lake Guntersville State Park), (2) owner, (3) type of recreation area (e.g., public park), and (4) acreage. The number of attributes for each data type ranged from 2 to 40. The GIS is capable of storing over 1,000 attributes for every point, line, or polygon stored in the system. The attributes can be used to retrieve selectively all or a subset of the mapped data, in accordance with combinations defined by the user. Conversely, the user can point to a mapped feature and request a report of all or a subset of its attributes. The link between mapped and attribute data is a powerful tool for selective retrieval, analysis, and display.

Many conceptual and technical problems were encountered in developing an integrated digital data base for Guntersville Reservoir. The data existed on a variety of source documents including unrectified aerial photographs and maps with varied scales, projections, and coordinate systems. For example, the landrights data for the Alabama portion of the reservoir were mapped at 1" = 500' on an Alabama East State Plane Coordinate base. The same data for the Tennessee portion of the reservoir were also mapped at 1" = 500' but on a Tennessee State Plane Coordinate base. Many of the descriptive data were mapped on USGS 7½-minute topographic quadrangle maps. These maps have a scale of 1" = 2,000' and use a polyconic map projection. Soil survey data were mapped at 1" = 1,667' on uncorrected aerial photographs. Integration of these sources into a common base would have been extremely difficult using manual graphic methods.

Table 1. Guntersville Reservoir Digital Data Base

(A) RESOURCE DATA:

Physical and Biological Data

1. Air Quality
2. Aquatic Plants
3. Fisheries and Molluscan Resources
4. Flood Elevations
5. Forest Resources and Research Areas
6. Prime Agricultural Land
7. Potential Erosion Hazard
8. Threatened or Endangered Species Habitats
9. Unique Biological and Geological Features
10. Water Quality
11. Waterfowl Habitats
12. Wetlands
13. Wetland Wildlife Habitats
14. Upland Wildlife Habitats

Social and Cultural Data

15. Archaeological Sites
16. Architectural and Historic Sites
17. Existing Forest Industries
18. Existing Industrial Areas
19. Existing Navigation Development
20. Existing and Planned Power Facilities
21. Existing Recreation Development
22. Water Intake and Discharge Facilities

Landrights and Political Boundaries

23. State, County, and Municipal Boundaries
24. TVA Reservoir Land (plan tracts)
25. TVA Reservoir Land (developed tracts)
26. TVA Reservoir Land (easements, leases)

(B) CAPABILITY DATA

1. Agricultural Capability
2. Barge Facility Capability
3. Forest Management Capability
4. Industrial Development Capability
5. Recreation Capability
6. Upland Wildife Habitat Capability
7. Waterfowl Habitat Capability
8. Wetland Wildife Habitat Capability

The World Mapping System (WMS) portion of the Intergraph software was used to integrate these data into a common digital data base. The Universal Transverse Mercator (UTM) coordinate system on a transverse mercator projection was selected for geographic referencing. UTM coordinates were selected instead of latitude/longitude coordinates because accurate acreage calculations were required. State plane coordinates could not be used because the reservoir covered portions of two States. The WMS software was used to transform all of the data from their source coordinates and projections into the common system. Differences in map scale were handled automatically by the software during data entry.

A more difficult problem was encountered when the same earth feature was represented in different geographic locations on different source maps. A prime example was the definition of the reservoir shoreline, particularly in shallow embayments. Significant differences were found in the shoreline location among the maps of surveyed property ownership, USGS 7½-minute topographic quadrangle maps, and Soil Conservation Service (SCS) county soil surveys. The differences were caused by a number of factors, including: (1) map scale, (2) mapping date, (3) reservoir water level at the time aerial photographs were taken, (4) natural processes of erosion and deposition over time, and (5) differences in human collection and interpretation of data.

For the Guntersville Reservoir data base, the TVA property ownership maps were considered to be the most accurate overall and were, therefore, used as the base to which all other data were registered. In addition, the ownership maps are legal documents used in daily land administration matters, which adds to their credibility. In some cases islands were adjusted to reflect changes that had occurred over time. The flexibility of the GIS was invaluable for registering all data to the selected base and inserting updated shoreline definitions where appropriate. In addition, the GIS served as a vehicle for recording and updating changes in land use, environmental conditions, and TVA landrights over time. These changes were made quickly and inexpensively.

Once the resource inventory was completed, it was used to support a range of reservoir land management activities.

<u>Reservoir Land Use Plan</u>

The purpose of the Guntersville Reservoir plan is to provide a decisionmaking tool that will enable TVA to better meet its responsibilities as a public agency and land manager and to expedite handling of requests for the use of its lands and waters. It is not a rigid "master plan." Rather, it is intended to have the flexibility to guide development, facilitate on-the-ground land management, and offer alternative sites for specific proposed land uses around the reservoir. The plan designates Guntersville Reservoir land for a variety of single and multiple land uses, guided primarily by views expressed by private groups and citizens, TVA land use policies and program objectives, and the inherent capability of the land to support various uses.

The GIS was used to support many activities during the reservoir land use planning process. The selective retrieval, analysis, and display capabilities of the system were used to manipulate the digital data base to aid land allocation. This included developing data interpretations such as prime farmland from detailed soil survey data, overlaying capability data with selected resource data to produce suitability maps for various uses, developing composite suitability maps that identified competition for land and potential compatible and incompatible uses, providing graphic and textual material related to mitigation of the effects of incompatible use conflicts, updating the TVA landrights data to reflect new tract boundaries that resulted from the land allocation, and using the system's extensive graphic display capabilities to facilitate development of the plan map for the draft and final project reports.

Manipulating the data base by means of traditional manual overlay techniques would have been considerably more difficult and time consuming. To develop a manual data base would have required redrafting over 350 source documents into a set of 200 hand overlays, each covering four 7½-minute topographic quadrangle maps. Selectively retrieving subsets of data types (for example, separating those sites on the National Register of Historic Places from the overall historic resources data and combining them with other data) would have been impractical by manual techniques.

Land Management Prescriptions

The reservoir plan provides an overall context for the use of TVA-owned land. However, land management prescriptions must be prepared to guide on-the-ground land management activities consistent with the reservoir plan. For example, various tracts were allocated for forest and wildlife management. On these tracts TVA foresters and wildlife biologists work cooperatively to determine detailed site conditions and develop a management strategy for those resources while adhering to strict environmental quality standards. This process usually requires an identification of forest stands accompanied by a detailed forest inventory; analysis of existing and potential wildlife habitats; and analysis of erosion potential, visual sensitivity, and site accessibility. The data management and analytical capabilities of the GIS can be used to store these data and conduct needed analyses.

Assessment of Environmental Impacts

Each year TVA receives hundreds of requests for the sale, transfer, lease, license, or other use of its reservoir land. Requests include such uses as road, pipeline, and transmission line easements; commercial boat docks, piers, and launching ramps; public and private recreation facilities; navigation; industrial development; and municipal facilities. Assessment of potential environmental impacts associated with each proposal requires an intensive interdisciplinary review that often involves field investigations (especially for archaeological and wetland resources) and public involvement.

The GIS can reduce costs and expedite this review process by rapidly developing a package of mapped and tabular information related to any particular request. The information contained in the package forms the basis for a formal environmental impact statement (EIS) or other assessment document. With this package TVA program staff can rapidly assess potential impacts and respond quickly to land use requests. Staff attention can be devoted mainly to changes in conditions since the last update of GIS and to interpreting the consequences of proposed uses rather than to recompiling resource data. In addition, TVA field staff that have direct access to the interpretations on GIS made by resource specialists can respond immediately to some preliminary requests (by telephone, etc.). In this way it is possible to assist applicants in modifying or redirecting clearly undesirable requests before initiating the formal review process.

By using the GIS as a data integration tool, each reviewer can examine all aspects of the situation, not just those directly related to his or her specific expertise. The result is a higher level of understanding and concurrence among the specialists reviewing each action. GIS can also exhibit particular proposed uses in the context of surrounding land and water use. Reviewers must no longer look at these requests as independent, isolated entities; they can address the important question of cumulative effects caused by numerous actions in proximity to one another on TVA reservoirs. High quality GIS graphics custom-tailored to each review highlight important issues much more effectively for consideration by all reviewers and also communicate the results of the review to field staff, TVA management, and the applicant.

COSTS AND BENEFITS

The most expensive aspect of implementing such a system for reservoir land administration is development of the digital data base. The total cost of using the GIS for Guntersville Reservoir was $100,000. Of that total, 65 percent, or $65,000, was required to build the digital data base. Landrights data alone accounted for $30,000. As such, the cost effectiveness of using such a system for reservoir land administration is dependent on the multiple use of the data base for planning, land management, and environmental assessment. To maintain the system's usefulness over time, the data base must be constantly updated to reflect changes in conditions. The cost of updating the data base for Guntersville Reservoir is less than $5,000 per year.

One-time use of the system--to aid development of the reservoir plan only--is more costly than using comparable manual techniques. However, when GIS is used to support a full range of reservoir land administration activities over time, it becomes a very cost-effective tool. For example, selective retrievals, analyses, and graphic displays of data in response to requests for the sale, transfer, or other use of reservoir land cost $50 to $350, depending on the nature and extent of the proposal. This cost is well below that of comparable manual methods.

CONCLUSION

Computer-aided geographic information systems such as the one used by TVA offer an effective tool for integrating and interpreting the large amounts of basic resource data necessary for sound planning of multiple-use land management. Cost effectiveness is further increased if the data bases developed for planning are also designed and maintained to support long-term land management and administration activities. Use of geographic information systems for land management will become more commonplace as managers discover the long-term economic benefits of their application.

MAPPING THE URBAN INFRASTRUCTURE

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ABSTRACT

Urban administrations, faced with increasingly complex problems in the expansion, upgrading and maintenance of the urban utility network, are seeking new and innovative means of obtaining fast, accurate and up to date facilities data. The development of modern electronic surveying and computer mapping capabilities have provided powerful tools to meet these challenges without major increases in human resources. This paper discusses a solution to this problem which is currently being implemented jointly by the Province of Alberta and the City of Edmonton. It briefly describes the urban survey and mapping program being carried out by the province and discusses the development of an urban utility cadastre, which is a sub-system of the City's Geographic Base Information System. Included is an evaluation of the benefits of the technological and procedural approaches adopted.

INTRODUCTION

The development of computerized mapping and land information management systems has been facilitated in Edmonton, as in other areas of Western Canada, by the existence of a homogeneous, structured system of land subdivision. This system of land (i.e. cadastral) surveys, commonly called the "township system" was established prior to settlement, and in conjunction with the land titles system of registration, has provided one of the best documented systems of land subdivision in the world. In recognition of the growing need for coordinate referencing of land information, the Alberta Bureau of Surveying and Mapping has developed a comprehensive surveying and mapping program, commencing in the late 1960's. The scope of this program now includes:

- the establishment of a survey control (i.e. geodetic) network
- the determination of co-ordinates for all points in the land survey system
- the determination of co-ordinates of photogrammetric control points in aerial photography, and
- the development of a base mapping system.

Since the majority of land information records are linked to or described relative to the land survey system, the program has been designed to make the maximum use of that system in order to optimize the development of land information management systems.

This paper is divided into two sections. The first section gives an overview of the urban component of the province of Alberta's surveying and mapping program. The second section briefly describes the development of the City of Edmonton's Geographic Base Information System (GBIS), which has used the framework provided by the Bureau's provincial program to implement an urban information management system, and discusses the development of the Utility Cadastre sub-system of the GBIS.

URBAN SURVEYING AND MAPPING PROGRAM

The Intergovernmental Agreement. Alberta was one of the first provinces in Canada to recognize the need, and accept the responsibility, for providing assistance to urban municipalities to develop a surveying and mapping framework. This assistance is formalized through an intergovernmental agreement which defines the area of coverage and sets out the respective responsibilities of the urban municapality and the province, which are, in summary, for the municipality to:

- locate and install survey control markers,
- maintain the survey control network in perpetuity, and
- make ties from the survey control network to the land survey system,

and for the province to:

- perform survey measurements on and compute coordinates of the survey control markers,
- compute coordinates of the land parcel corners,
- establish a photogrammetric control data base, and
- produce and periodically revise standard map sheets to cover the municipality, consisting of cadastral (land survey), contour and orthophoto components.

The municipality provides partial funding for the last step. Once the coordinates for the survey control markers are published, the area covered by the Agreement is declared a Survey Control Area. The Surveys Act requires that any subsequent land surveys within such an area be tied by survey measurements to the survey control network. This provides the mechanism for on-going maintenance of the cadastral component of the base mapping system.

The intergovernmental agreements with Alberta's two major cities, Edmonton and Calgary, differ in several key areas from the standard agreement. These cities have significantly greater technical and fiscal resources than the smaller cities and towns of the province, and this is reflected in the level of assistance provided under the urban surveying and mapping program. The major changes include the deletion of the photogrammetric control data base and the contour and orthophoto components of mapping coverage. In addition, a modified cost and work-sharing approach has been adopted for the production of cadastral mapping.

The Production Process. Once both parties have signed the agreement to formalize their respective intents to establish and maintain the urban surveying and mapping system, the work proceeds as described in the following paragraphs.

A. Survey Control. Once the municipality has located and installed the survey control markers, conventional triangulation, trilateration and traversing techniques are used to establish their relative positions and tie the municipal network to existing first and second order markers of the national geodetic network in the area. Field procedures are designed to yield positions of the markers to third order accuracy standards, as defined by the Federal Surveys and Mapping Branch. Additional measurements are made to tie at least one monument in the land survey system to each new survey control marker. The survey field work is contracted to surveyors in private practice, with limited in-house staff resources being used for reconnaissance and quality control checks on contract returns. The field data are processed through a least squares adjustment program on the Alberta government mainframe computer, an IBM 3033, to produce final coordinates for the survey control markers. Subsequent computation provides coordinate values for the tie points in the land survey system.

B. Land Survey. A map manuscript is used as the primary source document for the computation of land survey co-ordinates. This manuscript shows all surveyed property boundaries from which stems current title to land, and is compiled from such source documents as plans of survey, certificates of title, judges' orders, and gazetteers. The objective of the computations process is to assess the data in the same manner as a registered land surveyor would assess evidence on the ground, and to distribute errors accordingly. Staff survey technologists use a computer system of interactive programs to compute coordinates on mainframe CRT terminals, with the coordinates previously determined for the tie points and the survey measurements shown on plans of survey as input data. Each coordinate point is given a unique code number, which is stored in the computer file and is shown on the map manuscript. The land survey coordinates are used for cadastral mapping purposes, and under certain conditions defined by legislation, for the re-establishment of lost survey monuments in the field.

C. Photogrammetric Control. Vertical aerial photography of the municipality (normally at a scale of 1:8 000) is obtained under contract with a private mapping firm. Survey control markers are targetted prior to photography, and serve as the basis for establishing the positions of artificial photogrammetric control points marked on the aerial photos. The controlled photography and coordinates of the photogrammetric control points establish a photogrammetric control (or aerial survey) data base, which is used primarily for the production of mapping but is also made available for such special applications as digital terrain modeling or computational analysis projects within the municipality.

D. Base Mapping. The base mapping system for urban municipalities includes cadastral (land survey) orthophoto, 1m contour components. The Three Degree Modified Transverse Mercator (3TM) projection system is used, with 1:1 000 and 1:5 000 being the standard map publication scales. The 1:1 000 map shows detailed cadastral information, while the 1:5 000 maps include various combinations of the generalized cadastral, the contour and the orthophoto components. Examples of the typical 1:1 000 and 1:5 000 map sheet contents are shown in Figures 1 and 2, respectively.

Urban base mapping is achieved through a combination of contract and in-house production. The orthophoto and contour components are supplied by mapping contractors, usually on a project basis, which also includes the establishment of the photogrammetric control data base. The cadastral map components are produced by staff cartographic technologists from the coordinates previously computed on the mainframe computer, using the Bureau's Geodigital Mapping System (GMS). The GMS consists of an 8-station Intergraph Corporation interactive graphics system and an off-line photo-plotter supplied by Gerber Scientific Instrument Company. The GMS was acquired with the objective of establishing a provincial digital mapping system composed of several data bases to fulfill large, medium and small scale mapping application requirements. The large scale data base, being developed through the mechanism of the urban surveying and mapping program, currently consists of cadastral and contour data, with other topographical and cultural information being captured in hard copy form as orthophoto imagery.

Program Maintenance. The utility of the surveying and mapping system as a basic framework for land information management is largely dependent on the currency of the data. The urban program has been designed to have this very critical on-going maintenance function built in. The municipality is committed to maintaining the survey control network by replacing disturbed or destroyed markers and increasing the network density in urban fringe areas as development occurs. As previously indicated, land surveyors are required by legislation to tie all new land surveys to the control network, which facilitates the Bureau's on-going revision of land survey coordinates. The municipality and the Bureau are jointly committed to periodically revising the mapping coverage, with improved cost efficiency being provided by the existence of the photogrammetric control data base. The GMS has not only enhanced the Bureau's ability to meet the demand for a wide variety of graphical outputs, but has also greatly improved turnaround on map revision.

Products and Services. Although the urban surveying and mapping program is primarily designed to meet the needs of urban administrations, the available products and services are also used widely by such groups as land surveyors, engineers, planners, land developers and computer service bureaus. Survey control products include individual marker identification (ID) cards, and coordinate listings in hard copy or magnetic tape format. Adjustment statistics are also available for more scientific uses. The standard land survey product is a hard copy or magnetic tape coordinate listing, with computer-generated line connections to become available within the next year. Although the Bureau's copies of photogrammetric adjustment data and controlled photo diapositives are available to users, a system is currently under development which will provide a more formal service for users of the photogrammetric control data base. This will include access to an onsite point transfer device for transfer of control to the user's own photography, and provision of photogrammetric control point coordinates as a hard copy computer printout or on magnetic tape. The standard mapping products are diazo copies of 1:1000 and 1:5 000 cadastral maps and lithographed copies of 1:5 000 orthorphoto-line maps. Digital copies of GMS files of cadastral and contour data are also available on magnetic tape. In addition, a service is available for the municipalities to obtain various combinations of the data on film, in a range of scales, at the cost of materials. All products are available at nominal costs, with access restrictions limited to ensuring that users acquire the most current data and use it within normal accuracy limitations.

An Evaluation of the Program. The urban surveying and mapping program being carried out by the Alberta Bureau of Surveying and Mapping is expensive. The typical average implementation cost for a small municipality covering approximately 9 square miles is $200 000, with the Bureau and the municipality funding 87% and 13% of the total, respectively. Justification of the program from a conventional cost/benefit perspective is virtually impossible, since many of the benefits are long range and are either non-quantifiable, or at best, very difficult to quantify.

During the initial planning stages of the program, considerable effort was expended in evaluating alternatives and in analyzing similar programs in Europe, and in other parts of North America. The long term value of coordinate referencing, and of integrated surveying and mapping systems, had been widely known and accepted for decades in many European countries, but North American examples of such systems were relatively few at that time. One alternative to the approach, was ultimately adopted, would include the production of uncontrolled or semi-controlled aerial mapping, on a local datum, and the development of cadastral mapping by the manual compilation of survey data. This approach has been implemented in other areas, and while having the advantage of increased economy, it has generally suffered the major disadvantages of very limited application and short term benefits. Fortunately the planners of Alberta's urban surveying and mapping system possessed the foresight to identify the shortcoming of such a program, and the perseverance to secure the level of funding necessary to develop the program to its present form.

Some of the major benefits of the program are as follows:

1. The integrated system has the necessary accuracy to be used, not only for planning and land management, but also as an engineering design tool.
2. It substitutes one accurate standardized map base for large numbers of non-standardized urban maps and plans, many of which are often of unknown origin or accuracy.
3. The survey control network provides an accurate, stable framework of points which can be used for the location or relocation of property boundaries and for a large number of municipal engineering and surveying projects in the field.
4. The existence of the mapping data base in digital form provides the basic component required for the development of computerized urban utility, assessment and taxation cadastres.
5. The surveying and mapping system reduces revision costs by establishing the necessary key elements to facilitate on-going maintenance. Long term commitment to program maintenance is ensured by the joint signing of the intergovernmental agreement.

For any program to maintain its effectiveness, it must be subject to periodic reviews in the light of changing user requirements and new technology. Alberta's urban program is reviewed on an ongoing basis and has been improved in several areas during the past twelve years. From the surveying viewpoint, survey control markers have been improved in design, their spacing adjusted to meet changing needs, and the methods of their positioning updated to take advantage of modern developments in EDM, satellite and inertial positioning technology. From a mapping perspective, cartographic production has evolved from manual, through semi-automated to fully automated plotting of output, and significant improvements have been experienced in the accuracy and reliability of photogrammetric mapping. Standards and specifications have been amended and upgraded for both in-house and contract surveying and mapping work. A recent major revision of the intergovernmental agreement document has significantly improved the overall funding and administration of the program, as well as clarified the parties' roles and responsibilities. Further innovations, such as the use of "black-box" survey positioning technology and digital terrain modelling, will be implemented as required to ensure that the program continues to provide the necessary basic framework for the planning of Alberta's urban development.

EDMONTON'S GEOGRAPHIC BASE INFORMATION SYSTEM PROJECT

Background. The benefits of the accurate, up-to-date digital cadastral mapping system provided by Alberta's urban surveying and mapping program can be readily seen by providing a brief synopsis of the Geographic Base Information System (GBIS) currently being developed in the City of Edmonton. In 1977 a Metric Task Force recommended to City Council that a geographic base be developed with the framework for this system being the urban surveying and mapping program developed by the Province of Alberta. The data base system would coordinate all civic departmental metric conversion activities, develop metric standards for City maps and utilize computer-assisted mapping technology for conversion applications. In 1978 City Council approved a capital budget program for the Geographic Base Information System. The City of Edmonton commenced negotiations with the Province of Alberta to extend the urban surveying and mapping program, divide map production responsibilities and agree on suitable cost-sharing arrangements.

In order to complete the program by 1982, the City, through the G.B.I.S. Branch, purchased an automatic mapping system from Intergraph Systems Incorporated, consisting of a DEC 11/70 Central Computer Processing Unit, three graphics work stations and a Calcomp 960 plotter. Today the GBIS configuration consists of four networked systems and forty (40) workstations spread over eight City Departments, and capital funds have been approved to expand the project to five networked systems with over fifty (50) workstations by late 1982. Systems are currently operational in the Departments of Water and Sanitation, Edmonton Telephones, Edmonton Power and the central G.B.I.S. Branch. The Engineering Department has acquired a precise Cartographic Drafting System from Gerber Scientific Instrument Company in February of 1981 and in the late fall of 1982 will be installing a standalone graphics system for integrating geometric roadway design, engineering surveys and land-related information with the cadastral mapping data base.

The Utility Cadastral. The Geographic Base Information System encom passes a variety of graphical and informational sub-systems various stages of development. These include engineering design, tax assessment, street addressing and land-use and demographic mapping applications.

However, the foremost sub-system is the Utility Cadastral, which is being developed with input from Edmonton Power, Edmonton Telephones, the Water and Sanitation Department and the Engineering Department. Also, as of May of 1982, Northwestern Utilities, the privately owned gas company, has become an active participant in the project.

One of the most frequent problems in land-related information management systems has been the absence of accurate location of data. Consequently, the benefits of precise postional coordinates in a digital cadastral mapping system are numerous. One such benefit for the City of Edmonton is the accurate mapping of utility infrastructure data. The term infrastructure, as used in context of the Geographic Base Information System, applies to all man-made features of the landscape, including all of the "physical plant" necessary for the urban community - water, sewer, power and telecommunications facilities, oil and gas pipelines, buildings and transportation networks. Since location is the common attribute by which all infrastructure elements may be correlated, the large scale digital cadastral mapping system, developed by the City of Edmonton jointly with the Province of Alberta, provides the essential fabric for the development of the GBIS Utility Cadastre.

In order to effectively fulfill the corporate utility mapping requirements, the G.B.I.S. Project is structured along the following committee lines. A Steering Committee, comprised of Senior Management Levels in those civic departments with primary input responsibilities, was established to ensure that corporate planning and direction is maintained. To ensure that the policy decisions are effectively coordinated and implemented by all participants in the project, an Implementation Committee comprised of mid-management personnel was struck. This committee oversees the three working committee levels of Finance, Standards, and individual Departmental committees. Committee representatives established utility cadastre implementation procedures and schedules and developed protocols and levelling assignments for the layering of information. A special symbol and linework library for utility map products was also created. The major departments then proceeded to input utility data on the cadastral base from their existing records.

One of the problems foreseen in this method of implementation was the relative positional accuracy of each infrastructure element being entered. Since all departmental records were not uniform nor were they necessarily oriented to the provincial coordinate system, there existed the need for the corporation to strengthen its record system utilizing the highly accurate cadastral mapping base as the common tool. Towards this end, the Engineering Department researched several methods of acquiring, processing and displaying various types of digital infrastructure data on the cadastral base.

To achieve a more accurate and complete picture of the current infrastructure situation in the City of Edmonton, the Engineering Department proposed that the basis for the system must be surveyed location of the various utilities. Although it was recognized that many other important features of the utility such as material, capacity, installation and maintenance records were integral to the information management process, only the precise location of the physical plant would permit proper correlation of all data in an unequivocal manner.

An assessment of City utility records indicated that several of the common errors made in the acquisition and use of survey data were evident. In order for the survey community to provide a responsive need to engineering projects, it is most critical that the available human resources for surveying activities are utilized in the most cost-effective manner. Although surveying must be undertaken for every engineering project, the cost of the survey is generally a minor portion of the total project cost. However, if engineering projects are not supported by reliable survey data, delays and errors quickly escalate the total project cost. In addition, surveys should not be performed for single-purpose use without adherence to adequate geodetic support and accuracy specifications. If surveys are performed in a hapharzard manner, the results are never recoverable and the municipal taxpayer ends up paying handsomely for redundant surveys on the same project.

A more serious problem arising from the lack of systematic performances of survey can be seen when civic authorities must attempt to manage all aspects of the highly complex urban environment without accurate infrastructure information on the location, condition, and other related features of particular utility installations. If, for example, gas or pipeline explosions occur, as has been the case in several North American cities including Edmonton, there is a vital need to respond with prompt and highly correct emergency measures. Accurate mapping of the urban infrastructure permits technical staff, engineers, and civic administrators to utilize their time dedicated to a particular engineering project in the most efficient and effective manner.

With these important considerations in mind, the Engineering Department has embarked on new surveying, mapping and record system development projects to acquire and graphically display various types of infrastructure data. These projects are being implemented with a view towards utilizing the various human resources of private industry and the municipal government sector to their maximum potential. One such project, which utilized a combination of aerial mapping and modern ground survey techniques, is described in some detail hereunder.

Infrastructure Mapping - The Production Process. In order to create a utility map product which could be utilized for a variety of engineering and planning activities, the Engineering Department has established mapping specifications for the input of infrastructure elements to the cadastral mapping base. Survey specifications of data call for coordinates to be published using the 3° Transverse Mercator Projection with the usual 0.9999 scale factor at the reference meridian. Accuracy requirements are for features to be within 5 to 8 centimetres of their true position relative to the Alberta Survey Control system. These requirements allow both photogrammetric and land surveyors to acquire various sets of infrastructure data to be correlated with the cadastral framework. One surveying and mapping contract recently awarded in the City of Edmonton calls for the complete acquisition of digital data for utilities, buildings, curbs, hydrography and topography in a 2400 hectare area (2- 1:5 000 map sheets). The following briefly describes the surveying and interactive computer-assisted mapping procedures used in this infrastructure mapping process.

Prior to photogrammetry being performed, the survey company made a careful inventory of the street hardware that was known to exist. This was done by transferring the approximate location and type of data from existing City of Edmonton record plans to composite work sheets. With these sheets placed in a clipboard, the survey technologist then walked along each street checking off existing hardware and painting targets on selected items of hardware that were too small to be visible or may be obscured on a photograph. At this time, the control markers required for aerial triangulation were also targetted. Control markers, water valves, or buried street hardware were located using an electronic pin finder. Hardware not shown on the composite work sheet but clearly existing on the ground was added, while hardware not existing on the ground but shown on the sheets was noted.

New aerial photography was undertaken to C.A.A.S. (Canadian Association of Aerial Surveyors) specifications and at a scale of 1:3 000. The digitization of the street hardware, building, curbs, contours, and hydrographic features was undertaken using semi-analytical stereoplotters and the digital data stored on a 9-track magnetic tape along with added codes or identifiers for each set of requested information. The magnetic tape was then turned over to an engineering services sub-contractor whose interactive graphics hardware configuration closely matched that of the City of Edmonton. All cadastral base map files covering the project area were forwarded to the sub-contractor to separate the survey data into the appropriate files and levels. The City of Edmonton also made the firm familiar with all naming conventions, symbol or cell libraries, utility label definitions, working units, control parameters, and line weights and styles.

After the initial preparation of the graphics file by the mapping technologist, a ball point plot was returned to the survey firm for corrections. Additional survey work, if required, was performed using a "total station" surveying instrument consisting of theodolite, electronic distance measuring unit and digital data recorder. A revised plot was then forwarded to the Engineering Department who in turn edited the sheet for survey accuracy and completeness. Once again discrepancies were noted and returned to the survey firm where supplemented ground survey or additional field checks were performed. Corrected data was returned to the Engineering Department, interactive edit modifications were completed, and additional linework and annotation attached by the individual utility departments. A final photo light beam plot was then generated by the Gerber Cartographic Drafting System and photomechanically reproduced for record purposes. Examples of final utility maps are shown in Figures 3 and 4.

Evaluation of Infrastructure Mapping Project. The results of this and all other digital surveying and mapping projects undertaken as part of the corporate Geographic Base Information System have conclusively demonstated the need for future infrastructure acquisition, information processing and map creation projects to be continued using similar types of methods and procedures. The inherrent value to engineering projects can be summarized as follows:

1. All infrastructure data can be accurately captured terrestrially (ground survey) or photogrammetrically and can be supplemented by conventional field survey to provide 100% completion of utility information. This information should be surveyed to third order accuracy specifications which enables the infrastructure coordinates to correlate within acceptable survey deviation with the property (cadastral) boundaries.

2. Using automated survey practices which require the derived coordinates of the utilities to be connected to the survey control network means that this information can be accurately related to any other information on the city fabric which may be integrated at a later date.

3. Future changes to the urban infrastructure, whether they be for a minor or major undertaking, can always be surveyed to the same common specifications and result in new sets of data which can be easily integrated into the Utility Cadastre Sub-System.

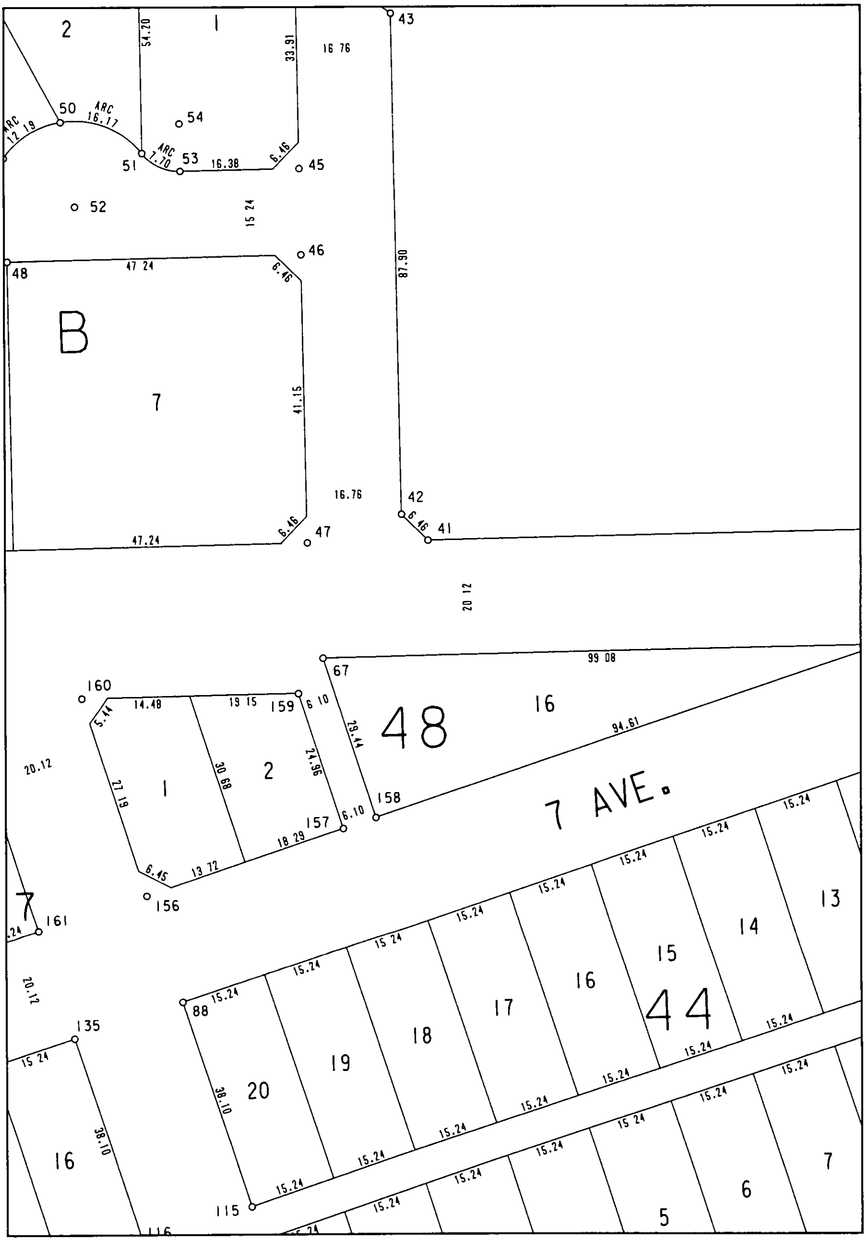
4. The primary role of the interactive graphics system is to process and eventually store the vast amounts of utility data which must be collected in the City of Edmonton. The computer graphics system also enables the municipality to simplify the production and maintenance (updating) of utility maps.

   The computer graphics system can readily accept large amount of data which can be quickly disposed into graphics files for rapid access and retrieved by technicians, designers, cartographers, or engineers to complete any pre-determined project function. This function may be related to mapping and/or engineering activities such as record system development or geometric roadway design. The graphics terminal operator can easily manipulate various types of information to conform to the requirements for the user.

5. The computer plotting and drafting system provides the most modern, "state-of-the-art" technology for the generation of various types of maps, engineering plans, and utility drawings. The system accuracy, speed and flexibility combine to provide a most efficient drafting tool for engineering utilization.

5. By utilizing the services of private survey firms and engineering companies engaged in similar interactive mapping applications, the compatibility of systems makes possible the smooth transfer of data with only minor software development required. This minimizes the quality control required of the municipality and enables mapping personnel in the City to complete the massive undertaking of utilily record conversion in a shorter period of time.

In summary, it is recognized that the total acquisition of complete utility infrastructure data utilizing the innovative techniques described above is very costly. However, it is much more economical to perform one survey to capture large amounts of information rather than extracting redundant survey data for single applications. A key to the continual development of the digital Utility Cadastre Sub-System in the City of Edmonton is to ensure that technical legends or accuracy codes are available to inform the user of the reliability of the information or from what source it is derived. As part of the total input in the Utility Cadastre Program for the G.B.I.S. Project, the Engineering Department is committed to achieving many of these goals. This will involve the active inter-relationship of personnel in both the surveying and mapping community and all engineering project staff in the City of Edmonton. Interactive graphics and computer drafting systems have provided a most powerful tool to effectively deal with the much sought after dynamic information system that is indespensible to rapidly growing municipalities. The involvement of man conversing with machine optimizes the capacity of both towards achieving higher levels of productivity within the complexities of rapid technological growth in the surveying and mapping industry.

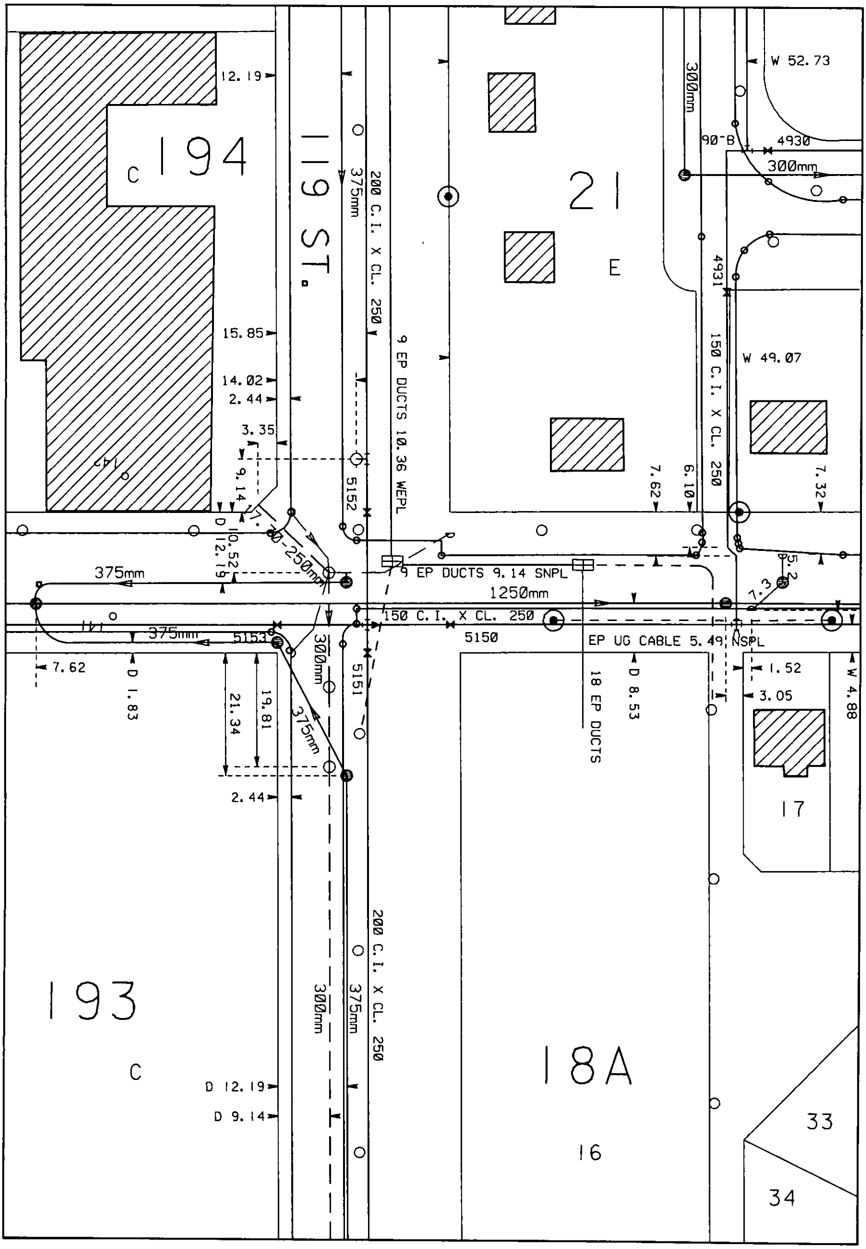


PORTION OF A TYPICAL 1:1 000 CADASTRAL MAP

FIGURE 1

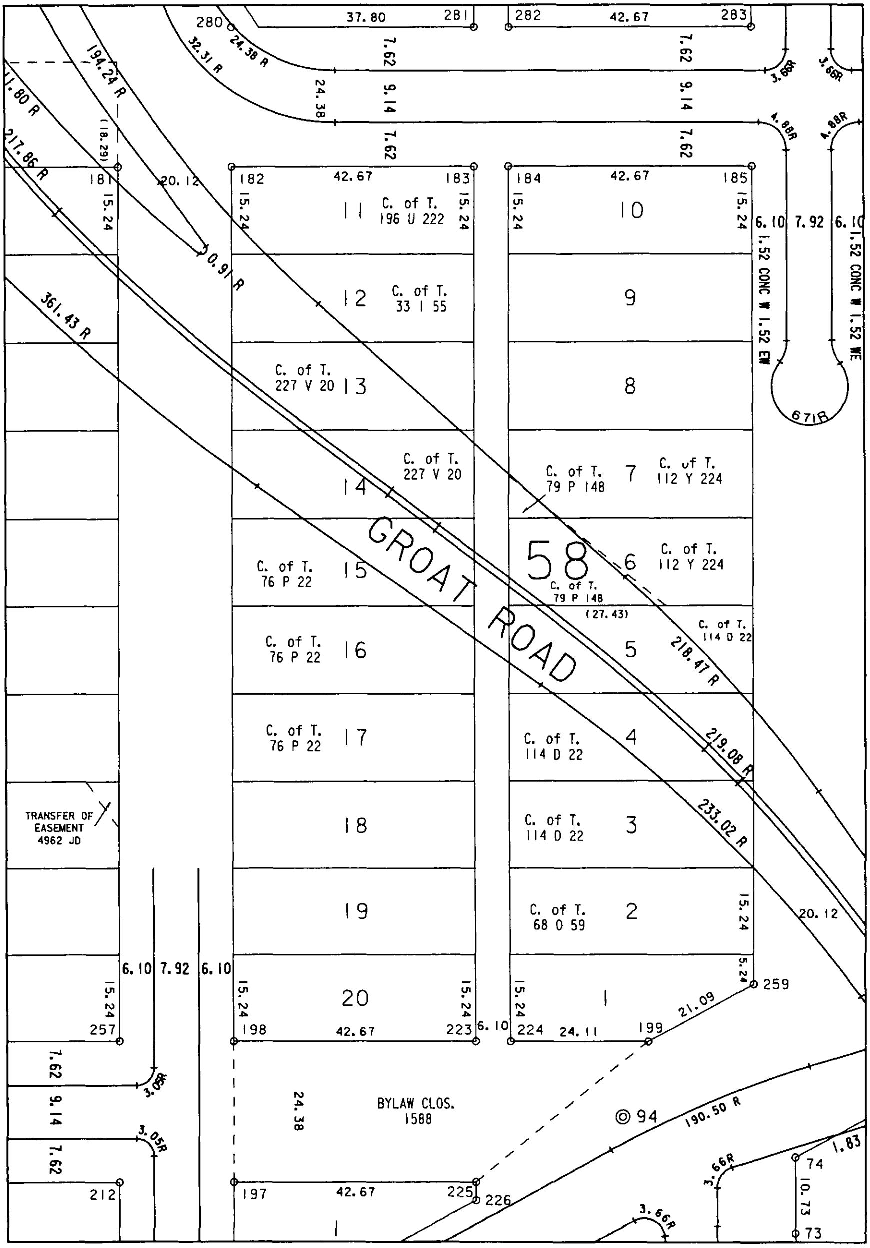
PORTION OF A TYPICAL 1:5 000 ORTHOPHOTO-LINE MAP

FIGURE 2



PORTION OF 1:1 000 UTILITY CADASTRE

FIGURE 3



PORTION OF 1:1 000 CADASTRAL STREET INVENTORY

FIGURE 4

THE EVOLUTION OF RASTER PROCESSING TECHNOLOGY WITHIN THE CARTOGRAPHIC ENVIRONMENT

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Mr. Kolassa received a B.S. in Business/Public Management from the State University of New York, College of Technology in 1982. He is currently serving as a Senior Programmer for Synectics Corporation, performing evaluation research in raster data structures and raster processing technology. Prior efforts have included programming for automated cartography, automated graphic data handling, and imagery exploitation experimentation systems. He is also a member of the National Computer Graphics Association.

ABSTRACT

As we move towards a higher degree in automation and sophistication, the digital cartographic environment will place increasing demands on raster data. A sound base from which to further cartographic raster processing is the knowledge acquired from past raster R&D efforts. However, the approaches taken have not totally resolved the associated problems of raster data nor do they support effective human interaction. With this understanding, the components of a conceptual raster system aimed at overcoming the problems to support the cartographic production community is explored.

INTRODUCTION

This paper will trace the evolutionary path of raster processing within the discipline of automated cartography. The emergence and subsequent development of raster technology in the cartographic production community will be presented. This background discussion is followed by a look at the current state of raster cartography and the major obstacles that still exist. Future directions are explored through presentation of a conceptual cartographic system for current and future needs.

EMERGENCE OF RASTER PROCESSING IN CARTOGRAPHY

Early digital cartographic efforts began by paralleling the manual cartographic process. Features were digitally recorded as vectors or lineal chains in the same way a cartographer would draft them. This allowed for the natural conceptualization of digital data as features and was precipatated as a result of functions which were implemented by those trained in manual methods; and the hardware that was readily adaptable to the replication of manual methods (Pequet, 1976).

Although automation had been introduced, data capture was slow and error prone due to the necessity of human intervention. Consequently, efforts were launched to develop new methods and technologies which might offer a more productive alternative. The result was the identification of raster technology to rapidly extract digital data from analog sources. Thus, early cartographic raster processing was founded on the development of raster scanning hardware (see Figure 1).

The early sixties produced several raster scanners which were able to sample cartographic source material and digitally record the presence or absence of cartographic features. Initial applications of the output focused on map duplication purposes. Foremost was the raster digitizing of cartographic manuscripts to produce color film separations (Palermo, 1971; Clark, 1980). Data capture rates were significantly higher than manual digitizing but were offset by the expense of early scanning equipment and cumbersome editing procedures.

A major obstacle in the use of raster data for other applications was the inability to perform feature or segment manipulations on raster elements in a fashion similar to most cartographers. In an attempt to solve this problem, several efforts were made to convert raster scanned data into the familiar representation of vector chains. The raster-to-vector conversion processes typically encountered two problems: a high processing overhead and the difficulty associating attributes with newly created vector chains.

CONTINUED DEVELOPMENT

Despite the problems inherent in the use of raster data there has been a continuing trend towards raster processing in the cartographic environment. This is primarily due to the increasing demands placed upon the cartographic production community. Also contributing to the continuance of raster processing were efforts targeted to resolve the problems through either hardware or software as shown in Figure 2.

Much of the hardware advances in the past decade has revolved around the data capture issue. Raster scanners have increased in performance and resolution while declining in price since the advent of several commercial firms into the market. Other devices capturing data in a raster format are video cameras (frame grabbers) and remote satellite sensors such as Landsat. These accomplishments have served to accelerate the capture of data in a raster format.

Advances in hardware to facilitate the manipulation of raster data has also been a driving force. High resolution CRTs, raster plotters and hardcopy devices, and the use of video offer a number of options for graphic output. Array processers and mass storage devices have

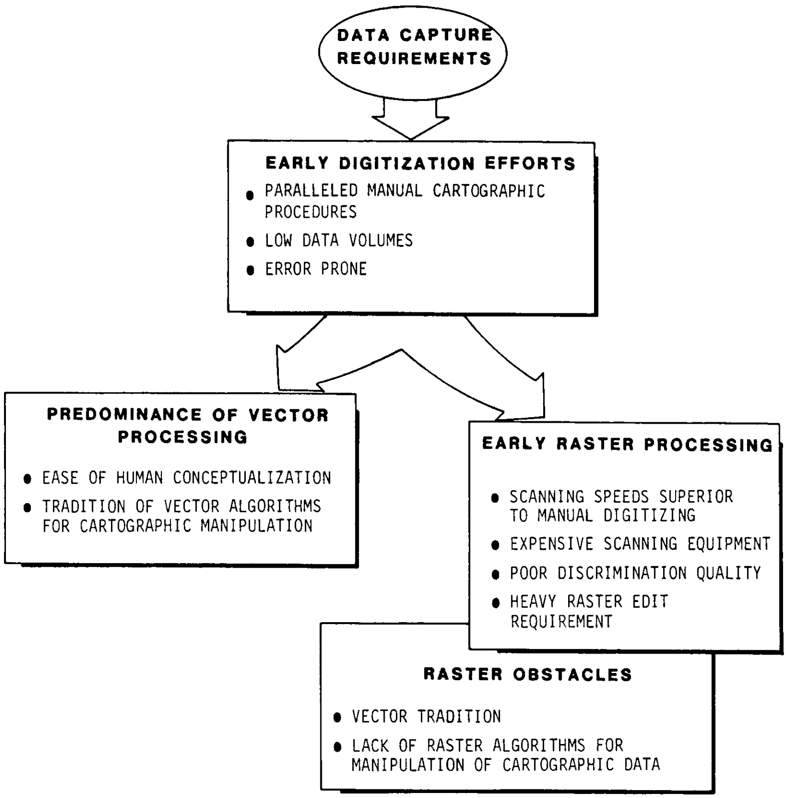

Figure 1. Early Data Capture Processes

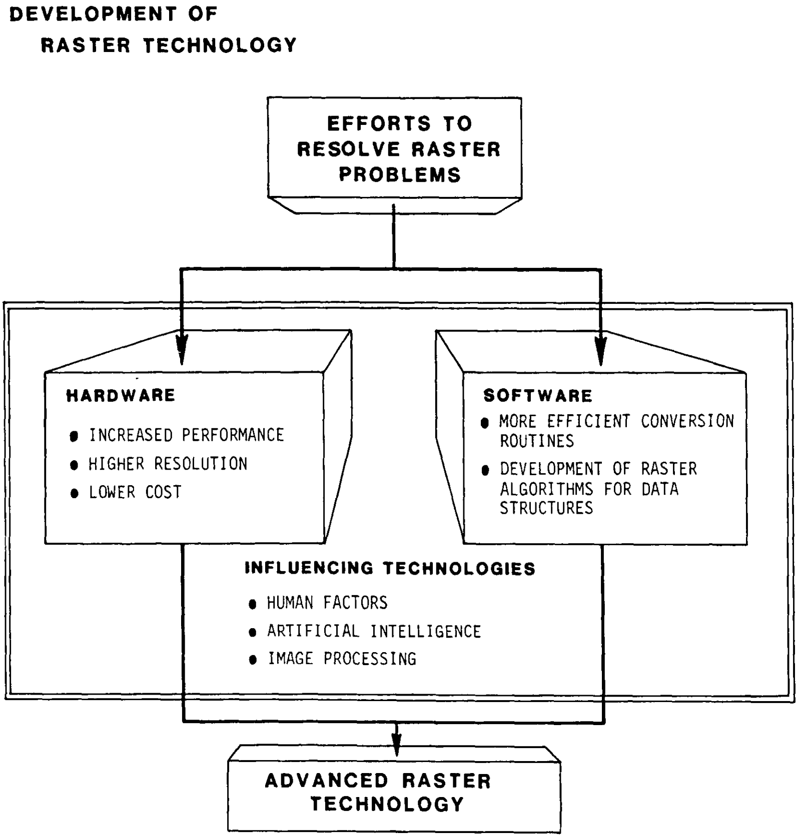

Figure 2. Development of Raster Technology

increased processing speeds and capabilities, while also exhibiting a decline in price.

In conjunction with improved hardware there has been increasing research into raster data structures and algorithms. More efficient conversions between raster and vector have been developed and implemented. The past several years has also produced interesting work in the area of data structures and algorithms which retain the data as raster elements. This approach offers a more efficient interface between the user and the data. It is perhaps this research that holds the greatest promise for the continued emergence of raster processing in the cartographic environment.

The development of raster processing has also been influenced by many other disciplines. For example, human factors engineering in relation to automated cartography has sought better human-machine interfaces to promote system efficiency and productivity. Ergonomic design considerations have been incorporated into raster devices to improve user interaction with the system. Techniques of artificial intelligence, pattern recognition, and syntactical analysis have been applied to raster cartographic feature recognition (Gilotte, 1979). Continued research which encompasses many fields will aid in solving the problems associated with raster data.

CURRENT APPROACHES

Presently, there are two distinct approaches to the utilization of raster data for cartographic purposes. The first, and most common, is seen in the raster-to-vector conversion systems. These systems usually employ a process of skeletonization to reduce lines to a single unit of width upon which line extraction and topology reconstruction is performed.

Conversion techniques insert an intermediate step prior to performing cartographic manipulations. In the compilation and revision environment where data is temporal in nature, additional processing leads to a corresponding decline in overall system productivity. While improved, the current raster-to-vector conversions still maintain some amount of processing overhead and encounter problems with attribute tagging, line coalescence in high density areas, line gaps and variable width lines, and processing times highly dependent on data resolution.

Furthermore, cartographic raster-to-vector conversion systems have primarily focused on contour and polygon type applications. This can be attributed to the specific rule sets which have been developed for these entities. More importantly, while the data is easily manipulated in vector format, its' graphical presentation to the user is foreign to its' true map symbology. As a result, the user is unable to interact with and manipulate data as it appears on the analog input source and final product.

The second approach centers around the implementation of systems where the raster format is maintained throughout the entire processing cycle. This combines the advantage of rapid data capture with quick access to the cartographic manipulation functions. However, this approach has also been stalled by problems with the manipulation of data as raster elements. Operations are usually performed on a color or pixel basis which does not afford the same flexibility as vector oriented systems.

Consider, for example, the problem of joining two features as depicted in Figure 3. Here an edit/revision to the data is required to complete the intersection of two roads. This join operation involves the identification of two features followed by the extension of a feature endpoint onto the second feature. We can easily envision the function to be performed but it is much more difficult to execute in a raster mode. Identifying a feature endpoint can be a cumbersome task where raster lines are more than one pixel in width. Other burdensome tasks are the determination of the direction to extend the endpoint and locating the connecting pixel on the second feature.

This example is further complicated in that the associated pixels represent dual cased roads. In this situation what ever is done to one side must also be applied to the other. Furthermore, when the connection is made, a deletion of pixels is required. It is problems such as this that restrict all raster systems from complete acceptance in the cartographic production environment.

FUTURE DIRECTIONS

Past efforts have laid the foundations and exposed the relevant truths for the raster processing of cartographic data. The major approaches will undoubtedly continue into the future, but more likely in specialized applications. Currently, the all raster systems appear to be the most beneficial when performing cartographic manipulations, especially compilation and revision functions. However, to overcome the related problems a new direction within the all raster approach is suggested. The knowledge base acquired from past efforts, along with an understanding of the problems and future needs, provides an ample starting point. Research at Synectics Corporation has sought to define the components of an all raster system based upon the total spectrum of available raster technology. The concept under consideration draws heavily upon the ideas set forth by Rosenfeld (1970) on connectivity, labeling, and segmentation. A brief overview of elements in this concept, as shown in Figure 4, is given in the following paragraphs.

The first step for any cartographic raster system is the capture of data. To make an all raster system as widely applicable as possible, it is beneficial to keep the data input specifications to a minimum. Therefore, the data input to Synectics' conceptual raster system is assumed to be gathered by an unintelligent scanner. This device would pass raster data to the system as a large NxM array reflecting the exact visual properties of scanned source materials.

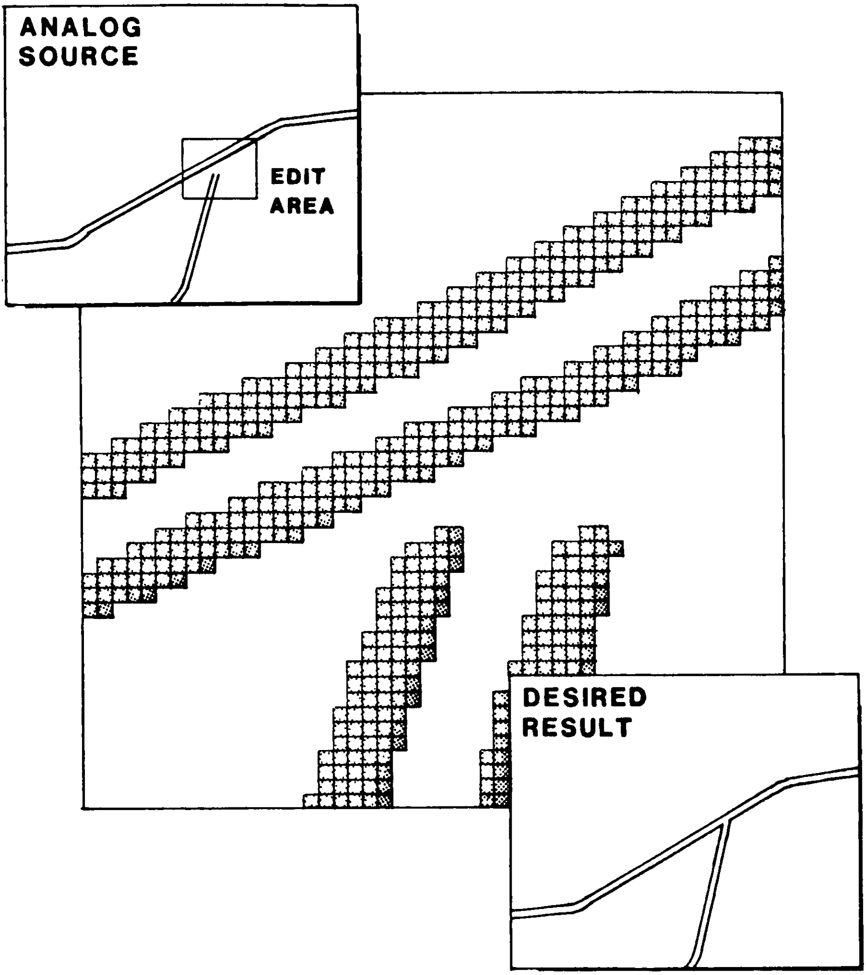

Figure 3. An Example Of Joining Two Features

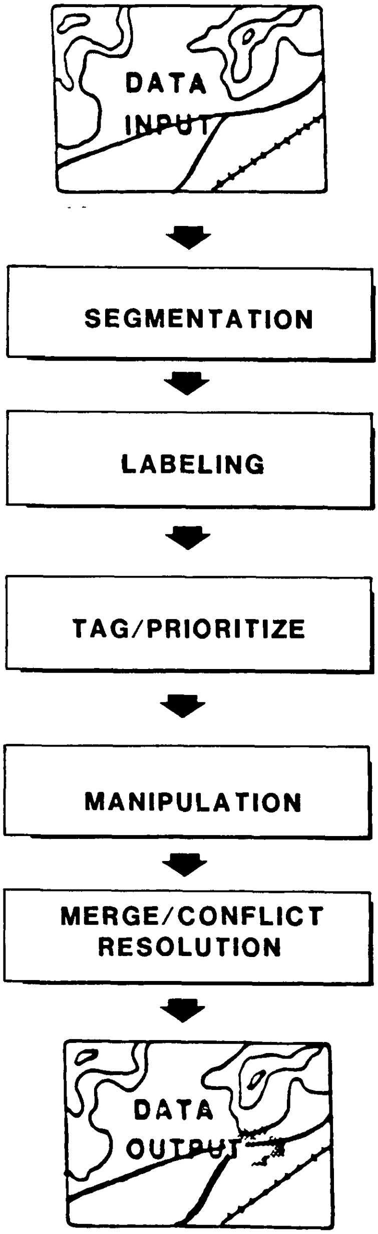

Figure 4. A Conceptual Raster System Data Flow

The next sequence of processes are required to prepare the data for the cartographic manipulation process. First, segmentation of the scanned data would form a number of subsets of pixels based upon pixel color (or gray shade) and halftone intensity. This process would result in an assignment of unique class numbers to each pixel and resolve conflicts in areas of overlays. Labeling would then be initiated to create subsets of associated pixels and assign unique identifiers to these subsets. Pixel associations would be made within similar pixel classes and among groups of pixels to form connected components. The segmented and labeled components would then undergo a tag/prioritize function to install a hierarchy among them. This ordering of components would serve to establish a priority among the cartographic entities to facilitate the cartographic manipulations.

Completing the previous tasks, the manipulation process for reviewing, correcting, and enhancing the cartographic data could easily be performed. It is this element of the conceptual raster system where the highest level of human interaction will take place. The operations included here fall into two categories: functions that act upon the data without changing data values and those which physically change the data. It is these functions which will require the greatest amount of effort in the future if we are to provide maximum human interaction.

Prior to data output, the recreation of the NxM visual array is necessary. This step would incorporate a merge/conflict resolution function to resolve conflicts among multiply defined pixels or coalescing features. The process would be able to draw upon the hierarchies established in the tab/prioritize function for some decisions while other conflicts may require operator intervention. Conceptually, this step is envisioned as merging multiple planes of data into a single plane, cleaning up any data discrepancies. This would expedite the output of raster data as either color separation lithographs or single sheets.

SUMMARY

Research over the past decade was first directed towards the design of hardware to perform data capture. Unique devices were built to scan cartographic data and convert it to a digital format. Following these efforts was a period of software development and implementation of raster based systems in direct support of the cartographic production community. As raster technology progressed, the associated problems of manipulating raster data surfaced. This spawned further research targeted to solve the problems, improve efficiency, and expand upon its capabilities.

The two predominant approaches which exist today are the raster-to-vector conversion systems and the all raster based systems. Each offers an advantage over the other but both share the common disadvantage of inadequate or cumbersome interaction between user and data. However, to fulfill the current and future requirements of the cartographic production environment, research points to the all raster approach to be the most promising. Systems development in this direction will be able to maximize the reduction in processing overhead for increased productivity. Secondly, all raster systems will allow users to manipulate data in a form which more closely resembles the analog source and final product. In order to support these functions, more emphasis is needed on developing algorithms and data structures which permit the user to think in vector while machine operations are executed in raster. Fundamental to this development are the concepts of connectivity, labeling, and segmentation.

ACKNOWLEDGEMENTS

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A DIGITAL DATA BASE FOR THE NATIONAL PETROLEUM RESERVE IN ALASKA

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ABSTRACT

The Bureau of Land Management (BLM) has the responsibility to prepare environmental assessments and environmental impact statements in support of the upland oil and gas leasing program on public lands. One of the first areas being leased in Alaska is the 23.5 million acre National Petroleum Reserve in Alaska (NPR-A). A digital data base has been prepared for NPR-A. This digital base includes landcover, elevation, slope, aspect, NPR-A administrative boundary, 1:250,000 scale quadrangle boundaries, 8 lease study areas and 124 lease sale blocks. The landcover information is from classified Landsat data; terrain data are derived from digital elevation models; and boundaries are digitized from map bases. When making decisions to approve, disapprove or modify oil and gas activities in NPR-A, BLM is required by law to mitigate "reasonably foreseeable and significantly adverse effects" on surface values. A digital data base allows the resource specialist or land manager to foresee conflicts by analyzing the characteristics of an area which may experience oil and gas operations. Data of interest can be displayed in map or tabular format. The digital data base for NPR-A has been used in the preparation of the environmental assessment, evaluation of lease study areas, characterization of potential lease sale blocks, wildlife habitat analysis, road suitability, winter trail route selection, water supply for potential drilling sites, and viewshed analysis.

INTRODUCTION AND BACKGROUND

The Naval Petroleum Reserve Number 4 (Pet 4) was created by executive order in 1923 by President Harding. The purpose of this large reserve was to protect and retain as a national asset a potential petroleum supply for the Navy. Under Naval jurisdiction, geological and geophysical mapping and surveying was conducted by the U.S. Geological Survey (USGS) from 1923 to 1956. The Naval Petroleum Reserve Production Act of 1976 designated Pet 4 as the National Petroleum Reserve in Alaska (NPR-A) and transferred the area to the jurisdiction of the Department of the Interior. This act (Section 104(d)) authorized further exploratory drilling and seismic exploration under USGS supervision. The Act specified several areas of concern for subsistence, recreation, fish, and wildlife. Section 105 authorized a task force study to evaluate the overall resources and best uses for the land of NPR-A. This study was submitted to Congress in 1979 (U.S.D.I. 1979).

The Department of Interior's Fiscal Year 1981 Appropriations Act authorized the Bureau of Land Management (BLM) to lease up to two million acres by competitive bidding procedures. An environmental impact statement was not required for the leasing process for the first sales. BLM has prepared an environmental assessment as an aid for identifying sensitive areas and selecting lease sale blocks. A total of 4.5 million acres were offered for lease in the first two lease sales on January 27, 1982 and May 26, 1982. About one million acres were leased as a result of those sales. Further leasing in NPR-A is subject to completion of an environmental impact statement, of which the draft will be released in October 1982.

BLM has the responsibility for determining which lands will be offered for competitive sale, but subsequent management of the leasehold is done in concert with the Onshore Division of Minerals Management Service (MMS). The MMS is the Department of Interior's authorized representative on all activities associated with drilling and production. BLM authorizes support development, rights-of-ways, airstrips, camps, etc., which are ancillary to drilling activities. Surface management ultimately requires a sophisticated data base for the preparation of operational stipulations and the evaluation of routine field monitoring.

A decision was made to create a digital data base for NPR-A. The basic elements of the digital data base are landcover, elevation, slope steepness, and aspect. The landcover data were derived from digital analysis of Landsat data which USGS prepared for the Section 105(c) studies. BLM has incorporated digital topographic data with the landcover classification to prepare the digital data base for the 23.5 million acres of NPR-A. Additional data such as quadrangle boundaries, administrative boundaries and seismic trails have been added. This data base allows users to select only the desired set of features and to manipulate them for a wide variety of applications. This paper discusses the components of the digital data base, how the data can be manipulated, and several applications of the data base.

STUDY AREA DESCRIPTION

NPR-A is located on the north slope of Alaska (Figure 1) extending from the the crest of the Brooks Range to the Arctic Ocean. It is bounded on the west by 162° W longitude and on the east by the Colville River. It covers portions of three physiographic provinces: the flat Arctic coastal plain, the rolling foothills, and the rugged mountains of the Brooks Range. The area is drained to the north by several large rivers. It covers 23.5 million acres, comparable in size to the State of Virginia.

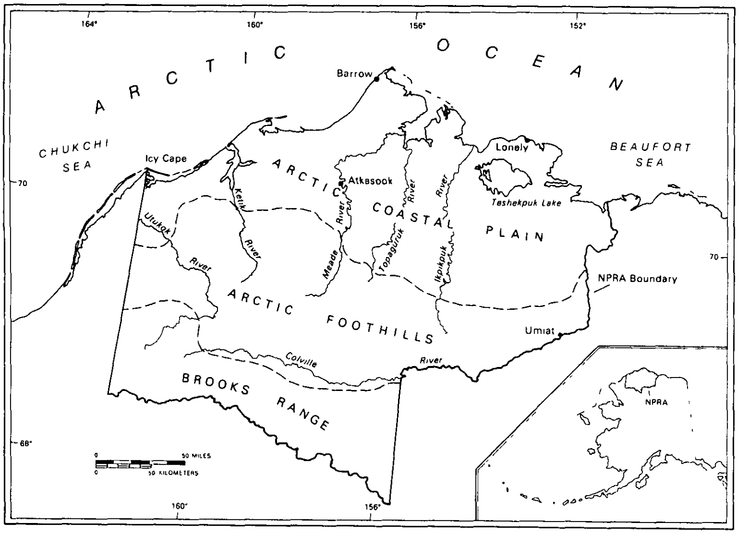

Figure 1. Location of the National Petroleum Reserve in Alaska (adapted from Morrissey and Ennis 1981).

The Arctic coastal area is a flat plain covering approximately one-half of NPR-A. The surface is characterized by thousands of thaw lakes and drained lake basins. There are meandering streams, aeolian dune features and polygonal ground. Polygonal ground is formed by ice wedges which increase in size with every freeze up and push the soil up into small ridges. The landcover is mainly tundra types with scattered brush. Tundra in polygonal ground is dominated by sedges (_Carex_ spp. and _Eriphorum_ spp.) associated with herbs and ericaceous shrubs and an understory of mosses and lichens. The soil is underlain by continuous permafrost (permanently frozen ground). Much of it is ice rich soil having lenses of pure ice below the surface. A thin layer (0.3-1 m) of surface soil, called the active layer, thaws each summer. Below the active layer, the ground does not thaw.

The foothills, south of the coastal plain, are a region of rolling hills, plateaus and ridges. These features are caused by the thrust faults in the southern foothills and the Colville geosyncline. The landcover of the region is dominated by tussock tundra with tall brush in the drainages and floodplains, and dry tundra or exposed barrens on the windswept ridge tops. Tussock tundra consists of cotton grass (_Eriophorum_ spp.) tufts (0.5 - 1.0 m high) with mosses and shrubs. The soils are generally poorly drained and underlain by continuous permafrost.

The Brooks Range Province consists of rugged mountains and glaciated valleys in the southern portion of NPR-A. These mountains are the Alaska portion of the Rocky Mountain Cordillera and have been glaciated. The mountains support a variety of landcover types with alpine tundra and barrens on steep slopes, mesic tundra and tussock tundra on the gentler slopes and valley floors, and high brush along streams and in river flood plains. The soils are generally thin except in morainal deposits, and are permanently frozen. Ice wedge features are not as common as on the coastal plain.

The area has been populated since prehistoric times by Native peoples. They have developed a subsistence life style which is still practiced in the region. Exploration for oil and gas and subsequent developmment of reserves can have many impacts on the people, as well as the land, vegetation and wildlife of NPR-A. There are potentially serious conflicts of this subsistence lifestyle with development impacts. Analysis of prescribed variables by using a geographically referenced data base can be an effective tool to aid managers in designing solutions to minimize such conflicts.

In addition to the socio-economic factors, there are unique problems for engineering and rehabilitation during development. The vegetation and peat mat forms an insulating layer for permafrost soils. When this layer is disturbed, thaw subsidence can result. Once begun, this surface degradation due to thermal erosion is very difficult to stop or stabilize. Measures must be taken during construction to minimize surface disturbance.

CREATION AND MANIPULATION OF THE NPR-A DATA BASE

The digital data base for NPR-A was created by specialists within the Bureau of Land Management, Alaska State Office, on the IDIMS computer system at the USGS EROS Field Office in Alaska. The software used (except for the terrain data entry) is available on most IDIMS systems. The data base is manipulated and output products generated on the IDIMS. The data are stored in a tape library for use to meet requests. Some of the data files have been transferred to other computers for analysis not available on IDIMS.

The USGS Geography Program created a digital classification of Landsat data for the entire NPR-A (Morrissey and Ennis 1981). This classification has ten landcover categories. Although regional in scope, it is much more detailed than the vegetation map previously available for NPR-A (Selkregg 1975). This landcover classification was made available to BLM by USGS for incorporation into the digital data base. The other primary data source for the NPR-A data base was digital topographic data produced by the Defense Mapping Agency (DMA). These data are available through the National Cartographic Information Center of USGS. The data are divided into twelve windows, one for each USGS 1:250,000 quadrangle in the study area. This procedure helped reduce the size of images needed for creation and manipulation of the data base. The data were resampled to 50 m pixels. Each data layer is registered to the map. This results in multiple data layers registered to each other and to a map base.

The landcover data from USGS were originally part of two large images. The data were windowed to quadrangle-sized images and registered to the map base using IDIMS geometric correction procedures. The data were spatially generalized to simulate a ten acre minimum mapping unit for use as landcover maps. Both the original and smoothed data are stored in the data base for each quadrangle. The ten land-cover classes in the data set are: deep water, shallow and sedimented water, ice, barrens, wet tundra, mesic tundra, tussock tundra, mixed tundra, fellfield, and high brush. Complete descriptions of these types are in Morrissey and Ennis (1981).

The DMA digital terrain data are recorded as elevation values in one meter increments. The pixel size of the original data was 6 x 3 arc seconds for the southern quad-rangles and 9 x 3 arc seconds for the northern quadrangles. The DMA data were in 1 x 1 degree blocks. Three or four blocks of data were mosaiced together to form the quad-rangle area. The data were rotated to north, resampled to the 50 m grid and registered to the map. During this work, software was developed at USGS EROS to automatically cal-culate control points and develop the transformation for registration. This procedure created the elevation data layer for the data base. The registered elevation data then were used to calculate slope steepness and slope aspect. The resulting images were registered to the map base and had 50 m pixels. Slope steepness data are in 1% increments when calculated from elevation. Slope aspect data are in 2° increments, with the 0 and 180 data values at true north.

The digital topographic data are an example of computer processing being able to calculate more detailed data than were in the original data source. The DMA data were digi-tized from the 1:250,000 topographic maps with 100 foot contours. The digital elevation data have been carefully examined by comparing the map with the video image. The data are adequate for the purposes of this data base to apply to the regional characterization. To avoid pushing the data beyond source accuracy, the topographic data are generalized when being used in manipulations of the data base. The elevation data are used in 25-30 m bands, the slope steepness data in 3-5% units, and the slope aspect data in 3-5° units. These aggregations are based on quali-tative evaluations of the data and the regional applications of the data base.

Additional geographic data may be entered into the data set by digitizing from maps. Data which have been incorporated into the NPR-A data base include quadrangle boundaries, the NPR-A boundary, lease study areas and potential lease sale blocks, a winter ice road corridor, and seismic trails. Other data which may be digitized include cultural resource archeologic sites, bear dens, peregrine falcon nests, caribou calving grounds and migration routes, drill sites, wild and scenic river corridors, potential road and pipeline corridors and land ownership status.

After the data base has been created, each quadrangle section can be manipulated to meet requests. Each data element for each quadrangle is stored as a separate image so that only the data of interest must be put on line for each request. Data base manipulations are accomplished using arithmetic, Boolean, maximum, minimum and mapping functions. Each request is different, requiring a different approach for the manipulation and generation of the output products. A good imagination and knowledge of the programs and data base are requisites for best success in manipulating the data base. After the final image has been achieved, final products such as tables of acreage or feature maps are made using a variety of output devices. Some of the manipulated images can in turn be entered into the data base for additonal manipulations.

APPLICATIONS OF THE DATA BASE

Continued exploration of NPR-A for oil and gas reserves, and the subsequent development of these reserves, will have varied effects on the land and the people. Many of the issues are complex and intermeshed with other issues. Products from the data base can provide information to assess the effects of development and identify conflicts.

Lease Sale Blocks

Prior to preparation of the environmental assessment, 5.8 million acres were selected with the high or moderate potential for oil and gas based on industry nominations. These lands are the lease study areas. The boundaries were digitized into the data base and landcover data extracted for them. The landcover data helped characterize the lease study areas. Landcover maps for each lease study area are in the final environmental assessment (U.S.D.I. 1981). One hundred and twenty four lease sale blocks of approximately 23,000 acres each were selected from the lease study areas for offering at the first two lease sales. Boundaries of the lease sale blocks were digitized. Landcover and slope steepness data were extracted for each block and reformatted to tabular reports. These data characterized the lease sale blocks prior to the sale to private companies. These data may affect which blocks are leased and the offering price based on exploration costs due to steep slopes or wetland areas, or flat terrain, accessibility of surface gravel deposits, and stipulations for use of sensitive areas.

View Corridors

The Colville, Etivluk, Nigu, and Utukok rivers are being considered for inclusion in the Wild and Scenic River System. One of the procedures is to establish a view corridor encompassing the area which can be seen from the river. Viewshed images for the entire length of the rivers were created by combining the landcover types of water, barrens, and high brush with elevation data. The willow

(*Salix* spp.) thickets along the river floodplains reach heights of 7 m and are the tallest plants in NPR-A. In areas of high brush, the view from a boat is blocked on that side of the river by the willows. Where no high brush is close to the river, the viewer can see the surrounding terrain. From the elevation data, it can be estimated how far and what features can be seen from various points along the river. This is taken into consideration when planning developments near the river.

Utility and Transportation Corridors

Development of large oil and gas discoveries in NPR-A will require a network of roads and pipeline corridors. The data base can be used to help select corridors to minimize engineering problems and environmental impacts. Road suitability analysis illustrates this by using slope steepness with other factors as are pertinent such as gravel deposits, water, wetlands or slope aspect. Several potential pipeline corridor routes can be compared with each other. The proposed corridors would be digitized and appropriate data elements extracted for each corridor. The percentage of desirable factors such as gravel sources or gentle terrain can be compared with undesirable factors of steep slopes or wetlands. The corridors can be overlaid with other data combinations such as the viewshed corridors discussed above, wildlife habitat, or privately owned land. These comparison data provide a manager with information to assist in selecting a route. Similar analyses can be done for winter ice roads and rolligon trails.

Materials Sites

A crucial public issue regarding NPR-A development is gravel. Gravel is needed for development of roads, pipelines, drilling pads, airstrips and camps. Thick pads of gravel are layed down on the tundra so that development activities will not disturb the insulating layer. The gravel pad protects the permafrost soils and prevents thermal erosion. The major source of gravel is the flood plains of large rivers which are part of the barrens type of landcover. Additional known subsurface gravel deposits could be digitized into the data base. These data can be used in siting development camps or evaluating the cost feasibility of developing an oil and gas reserve.

Water

Water is also needed for winter exploration and development. Although the area abounds with lakes and the soils are saturated, all of the water freezes in winter except in lakes deeper than 2 m. Landcover data and SLAR data (Mellor 1982) can be used to evaluate potential water sources and determine if conflicts exist between fishery and industry needs.

Wildlife Habitat

Wildlife species, such as caribou, moose, bear, and waterfowl, are an important renewable resource in NPR-A because they are part of the Native subsistence lifestyle. Knowledge of possible locations of critical wildlife habitat can be used to reduce foreseeable impacts when planning and monitoring oil and gas exploration and development activities. One example is spring habitat for moose. Within the context of the digital data base, this habitat has been defined as high brush on south facing slopes. The data manipulation involved several sequential steps. First, the south facing slopes were selected from the aspect data over the area of interest, then brush was pulled out of the landcover data. The two features were combined so that only the areas which had both attributes are shown. All water was added to the image as an aid for location. Since the data were in digital format, it was a simple matter to calculate the acres of each feature and convert to percentage area estimates to present the needed information in tabular format. When habitat is shown with gravel sources, potential conflict areas can be identified when the data is presented in map format.

Conflict Resolution

Two important types of applications envisioned involve 1) identification of conflict areas and 2) identification of areas for exclusion from a particular activity. Analysis of factors contributing to conflicts between development activities and other resources can enable informed decisions about the conflict, mitigating regulations, or alternatives. Areas which need to be excluded from some development activities may have one or more factors which can be assessed using overlaid data bases. These may include critical wildlife areas, cultural resource sites, or areas with wilderness values. These data can also contribute to design specifications or stipulations for development and rehabilitation.

SUMMARY AND FUTURE DIRECTIONS

The Bureau of Land Management, Alaska State Office, has created a digital data base for the National Petroleum Reserve in Alaska. The purpose of the data base is to provide a reliable and consistent regional data base in support of: 1) leasing for exploration and development of oil and gas resources in NPR-A, 2) planning, 3) monitoring and 4) day-to-day and long term management. The data base has elements of landcover, elevation, slope steepness, slope aspect, and various geographic and administrative boundaries. This data base is manipulated for a wide variety of applications in NPR-A including the leasing program, development constraints, and conflict identification. The existing data base serves as a framework for the inclusion of other data sets and offers potential for modeling. Data available on other computer systems may be tied in with this data set. Potential data sets are the land net and hydrography in the BLM computer at the Alaska State Office.

Point location data could be digitized. Non-graphic data could be associated with the point data. An example would be archeological sites with dates and materials information. All facets of the expanded data sets could be manipulated with statistical packages. Software needs to be developed to facilitate the exchange of data between computer systems and to allow additional flexibility in manipulation.

At present, creation and manipulation of this data base are done by a BLM staff of remote sensing specialists at the Alaska State Office. Capability of remote terminal access, manipulation, and generation of output products needs to be developed to allow direct accessibility to the data base by BLM staff specialists in the district offices. BLM is creating data bases for other lands in Alaska and a network of remote terminals to query and utilize these data bases will become more important in resource planning and management.

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AN EVALUATION OF AREAL INTERPOLATION METHODS

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ABSTRACT

In solving the areal interpolation problem, the overlay and the pycnophylactic methods are believed to yield more accurate target zone estimates than the conventional approach since these two methods preserve original source zone values. The accuracy of the target zone estimates resulted from these two methods are found to be related to the number and the area of split source zones and the variation in values between neighbouring zones.

INTRODUCTION

The problem of obtaining data for a set of areal units (target zones), e.g. political district data, from another set of areal units (source zones), e.g. census tract data, that is, the areal interpolation problem, has become an increasing concern in the field of geographic and cartographic information processing. This problem often arises when two or more sets of areal data have to be included in a study.

Conventionally, this areal interpolation problem is solved by some isopleth mapping technique. A mesh of grids is first superimposed on the source zones and control points representing source zones are assigned. A point interpolation scheme is then applied to interpolate the value for each grid. Finally, the estimates of each grid point are averaged together within each target zone, yielding the final target zone estimates. Problems associated with this approach have been discussed (e.g., Hsu and Robinson, 1970). The most critical one is that the original source zone values are not preserved before aggregating into target zones. As a result, the final target zone estimates are less predictable and the errors are likely to be higher.

Two other methods for areal interpolation including map overlay and pycnophylactic interpolation have recently been suggested (Goodchild and Lam, 1980). A common characteristic of these two methods is that the original source zone values are preserved. Such a volume-preserving characteristic is considered highly desirable for areal interpolation since subsequent estimation of target zone values is less subject to error. The target zone estimates obtained by these two methods have been shown to be more accurate than those obtained by using the traditional approach (Lam, 1980). Different sets of assumptions and problems, however, are involved in these methods, which will affect the quality of the final target zone estimates. This paper examines the major factors affecting the reliability of these methods. The procedures and characteristics of these two methods are first briefly discussed. The error factors are then identified and their effects are modeled and experimented using fractal surfaces.

THE OVERLAY METHOD AND ITS ERROR FACTORS

Suppose there are n source zones and m target zones. The areal interpolation problem is to obtain the target zone estimates, represented by a column vector $\underline{V}$ of length m, from the source zone value $\underline{U}$, a column vector of length n. The overlay method simply starts by superimposing the target zones on the source zones, and a matrix $\underline{A}$ consisting of the area of each target zone in common with each source zone (a_{ts}) can be constructed. For data which are in the form of absolute figures or counts, such as population and total income, an estimate of target zone t is obtained by:

$$V_t = \sum_s U_s a_{ts} / \sigma_s \qquad (1)$$

where σ_s refers to the area of the source zone s. In matrix representation, $\underline{V} = \underline{WU}$, where $\underline{W}$ is a weight matrix containing elements of a_{ts}/σ_s. The estimation procedure differs slightly for density data (e.g., population density) and ratio data (e.g., percent of male). The estimation formulae for these types of data can be found in Lam (1982).

It has also been shown before that for every target zone estimate, there is a theoretical maximum error range (Lam, 1982). For example, for data in the form of absolute figures, the maximum error range is simply the sum of values of all split source zones involved. For density data, the error range is equal to:

$$\sum_k U_k \, a_{tk} / \sigma_k \qquad (2)$$

where k refers to the split source zones involved in target zone t. T_t is the area of target zone t. In reality, the estimation error for every target zone estimate lies within the theoretical maximum and depends on a number of factors.

The most important error factor is that the overlay method assumes homogeneous source zones. This error factor is easily perceived and its effect on areal interpolation has been demonstrated (Ford, 1977; Goodchild and Lam, 1980). Unfortunately, the degree of homogeneity within source zones is always unknown since the source zones available are supposed to be the finest resolution one can obtain. This implies that the errors involved in the overlay estimates cannot be determined unless some known parameters which may serve indirectly as indicators of homogeneity are determined first.

Very few studies have been focused on the homogeneity of the areal units and its relationships with other factors despite its importance and frequent uses in many fields. Coulson (1978) was among the few to suggest that the size and the shape of the areal units are the two major factors in estimating the potential for variation within these units; the smaller and the more compact in shape the areal units, the lower the potential for variation within these units. These two factors have recently been examined by MacEachren (1982) and were further illustrated by his experiment. However, an independent study conducted by this author (Lam, 1982) did not support their findings. Thus the effect of size and shape on the homogeneity of areal units remains questionable. It is necessary to examine other factors.

Since the target zone estimates are solely dependent on the weights derived from the area of intersection, a close look of the form of the weight matrix $\underline{W}$ will be useful. For data in the form of absolute figures, perfect results can be obtained in two extreme cases; where the source zones and the target zones having the same size and shape (Fig. 1a), and where the target zones being simply aggregates of source zones (Fig. 1b). In these two cases, the non-zero entries in each column are all equal to 1. In other words, there is no split source zones involved in each target zone. Any deviation from these two forms of matrices will result in certain estimation errors for target zones. The general case would be when the source zones and the target zones have different sizes and shapes, so that the weight matrix has more than one non-zero entries in each row and column, with most of them smaller than 1 (Fig. 1c). It is therefore expected that the accuracy of the estimates will be influenced by the number of non-zero entries which are smaller than 1, i.e., the number of split source zones involved, and more split zones may imply more possible sources of error. Similarly, it is expected that the proportion of area of a target zone occupied by the split source zones will also affect the quality of the target zone estimates.

It should be noted that the above relationship will be biased by the "coast-line weave" or trivial polygon problem (Tomlinson, 1972). This problem arises when the same boundaries in reality diverge slightly because of source map errors, digitization errors, or difference in zone definitions. In such cases, most of the non-zero entries in the weight matrix are trivial and will not reflect the target zone errors that are potentially involved.

In addition to the number and the area of split source zones, variation in values between a particular source zone and its neighbors may also serve indirectly as indicators of homogeneity. This corresponds to one of Ford's (1977) findings in his study on areal interpolation using the traditional approach. It might be reasonable to expect that higher variation between neighboring zones may imply a rougher underlying surface, and the zones delineated from this surface will likely be less homogeneous. For the present problem, since only the split source zones will contribute to the error, the mean absolute difference between each source zone and its neighbors, d_t, will be used in testing the model. In short,

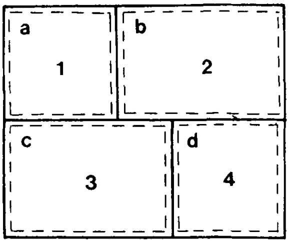
$$e_t = f(n_t, a_t, d_t) \tag{3}$$

where e_t denotes the error of the target zone estimate as represented by the difference between the estimated value; n_t, a_t are the number and the area of split source zones. Since there is very little knowledge about the manner in which the accuracy of the estimates are affected by these factors, a linear form of the above model will be examined at this preliminary stage.

THE PYCNOPHYLACTIC METHOD AND ITS ERROR FACTORS

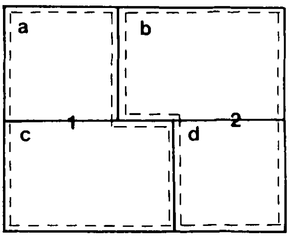
The pycnophylactic interpolation method was first suggested by Tobler (1979) for isopleth mapping and has recently been applied to areal interpolation (Goodchild and Lam, 1980). The method also utilizes an overlaid mesh of grids on the source zones. The grid values are esti-

a. Special case 1



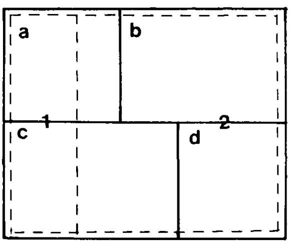
Target	Source a	b	c	d
1	1	-	-	-
2	-	1	-	-
3	-	-	1	-
4	-	-	-	1

b. Special case 2



Target	Source a	b	c	d
1	1	-	1	-
2	-	1	-	1

c. General case



Target	Source a	b	c	d
1	.6	-	.5	-
2	.4	1	.5	1

——— Source zone boundaries
– – – Target zone boundaries

Figure 1. Configurations of source and target zones.

mated according to two criteria. First, the resultant surface is required to be smooth using some governing density function. One type of smoothing condition can be obtained by requiring the value of any grid cell be close to the average of its four neighbors. Second, the sum of all the grid values within a source zone is required to be equal to the original source zone value, i.e., the pycnophylactic or volume-preserving condition.

In short, the interpolation procedure begins by assigning the mean density to each grid cell, and then modifies this by a slight amount to bring it closer to the value required by the governing density function. The volume-preserving condition is then enforced by either incrementing or decrementing all of the densities within individual zones after each computation. Since the assignment of values for cells outside the study area will affect the measure of smoothness near the edge and consequently inward, the selection of a boundary condition should be careful. Different boundary conditions can be used. For example, a zero density may be assigned to outside areas when dealing with a study area bounded by water. The above procedure can be used for data in the form of absolute figures and for density data. For ratio data, similar to the overlay method, two separate procedures for the numerator and the denominator are required.

Compared with the overlay method, the pycnophylactic method represents a conceptual improvement since the effect of neighboring source zones have been taken into account, and secondly, homogeneity within zones is not required. The overlay method assumes a discrete surface with breaks along the source zone boundaries and the pycnophylactic method assumes a smooth surface as designated by the smooth density function. It is clear that the smooth density function and the boundary condition imposed are again only hypotheses about the surface and may introduce estimation errors for the target zone values.

Similar to the overlay method, the theoretical maximum error range for every target zone estimate, in the case of absolute-figure data, is the sum of values of all split source zones involved. For density data, the error range is the same as equation (2). This is in fact a fundamental characteristic of the volume-preserving areal interpolation methods. Again, it is expected that the number and the area of split source zones will affect the accuracy of the target zone estimates, though the manner and the magnitude of their effects may be different from those on the overlay method. For the factor of the variation between a source zone and its neighbors, since the pycnophylactic method assumes a smooth surface, it is expected that higher variation imply a rougher surface and as a result a higher chance or error. Hence, the linear model used for overlay may also be used for pycnophylactic in evaluating the reliability of these methods.

EVALUATION AND DISCUSSION

Evaluation of the above model includes two steps. First of all, computer-generated fractal surfaces of specific demensionalities were used. These surfaces are believed to be very useful for simulating the surface of the Earth (Mark, 1979). Higher dimensionality ($D>2.5$) means a rougher surface and lower dimensionality ($D<2.5$) results in a smoother surface. A dimensionality of 2.3 is found to correspond to most real-world surfaces (Mandelbrot, 1977). Four surfaces of dimensionality D=2.1, 2.3, 2.7, 2.9 were generated in the form of 30x30 grids using Goodchild's algorithm (1980) (Fig. 2a). They were then partitioned into rectangles of different sizes to represent source and target zones. Figure 2b is an example of the hypothetical source and target zones. In this case the true values for target zones are known. The absolute difference between the estimated and the true target zone values as a percent of the estimated value (APE), the number and the area of split source zones, and the area-weighted mean absolute difference between each split source zone and its neighbors were calculated accordingly.

Initial stepwise regression of these variables show that there is only a moderate to weak relationship between the error as represented by APE and the three independent variables, and this relationship is unstable, with multiple R's ranging from 0.24 to 0.91 (Table 1). Secondly, surface complexity seems to have little effect on the behavior of the model since R's do not vary significantly among the four surfaces. This is mainly due to the fact that the surfaces were further partitioned in a random manner and the effect of surface complexity has thus been reduced.

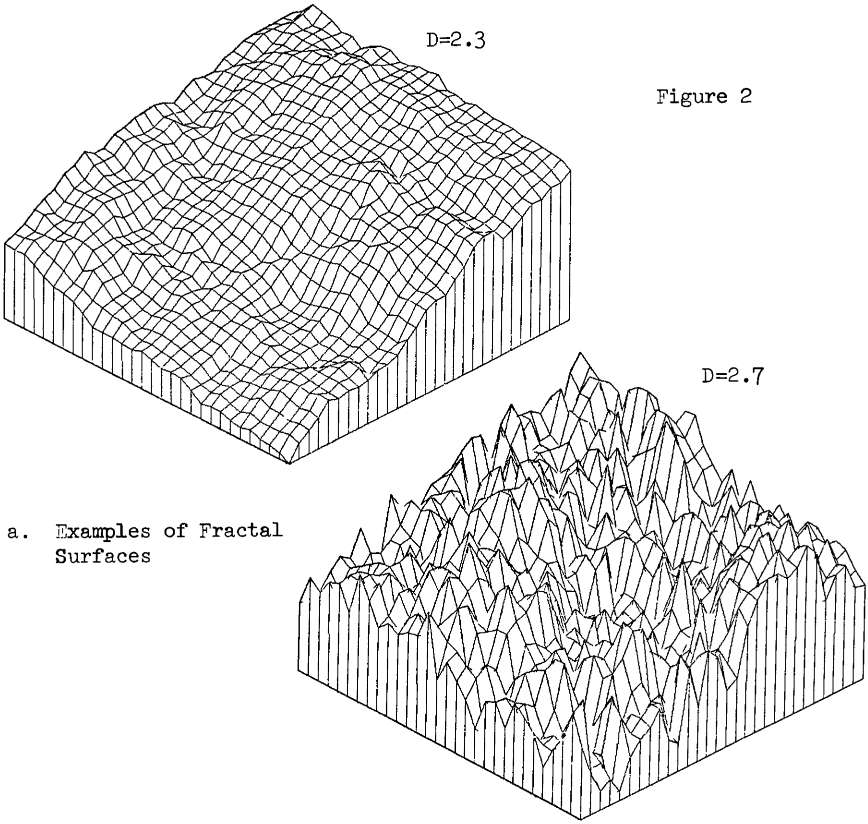
Table 1 : Summary Statistics

Surfaces	Size: Source Zone	Size: Target Zone	#source/ #target	Multiple R's: Overlay	Multiple R's: Pycno.*	Multiple R's: Overlay	Multiple R's: Pycno.**
	5x5	7x7	36/25	0.54	0.27	0.49	0.44
D=2.1	4x4	7x7	64/25	0.49	0.91	0.99	0.95
	5x4	7x5	48/30	0.47	0.65	0.62	0.35
	5x5	7x7	36/25	0.51	0.44	0.44	0.38
D=2.3	4x4	7x7	64/25	0.23	0.90	0.99	0.95
	5x4	7x5	48/30	0.35	0.24	0.74	0.57
	5x5	7x7	36/25	0.32	0.24	0.54	0.49
D=2.7	4x4	7x7	64/25	0.44	0.91	0.99	0.94
	5x4	7x5	48/30	0.57	0.47	0.60	0.50
	5x5	7x7	36/25	0.40	0.23	0.54	0.50
D=2.9	4x4	7x7	64/25	0.56	0.92	0.99	0.94
	5x4	7x5	48/30	0.38	0.60	0.70	0.58

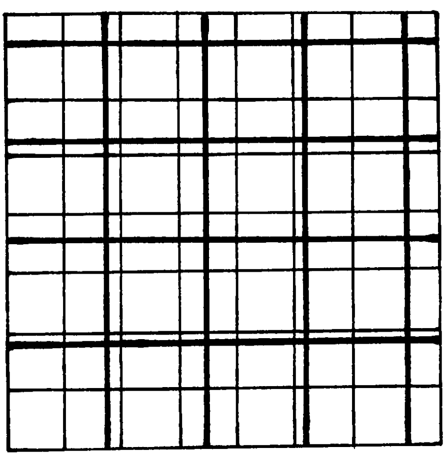
* Multiple regression using APE as dependent variable.
** Multiple regression using adjusted APE as dependent variable.

A third finding of this initial analysis is that the model performs better for overlay than for pycnophylactic, with exceptions, occur in the cases of 64/25 #source/#target zones. In these cases, R's are unusually high (>.90). A close examination of the values in these cases indicates that most source zones along the border are unable to maintain the original values after 100 iterations in the pycnophylactic interpolation process. This is largely due to the fact that the 30x30 grid mesh used is not fine enough for maintaining both the volume-preserving and the smoothing conditions. As a result, the estimation errors for the target zones along the border are higher, and coincidently, the number of split source zones are also smaller for these target zones, yielding higher R's than other cases. The failure to preserve the original source zone values may also contribute in part to the poorer performance of the model for the pycnophylactic method.

Figure 2



a. Examples of Fractal Surfaces



b. Hypothetical Source and Target zones

The moderate to low R's resulted and the instability of the model may be due to a number of factors, including for example incorrect form of the model, inappropriate definitions of the dependent and the predicting variables, and exclusion of some other factors. Therefore in a second step, an adjusted APE was used. The adjusted APE was derived by dividing the original source and target zone values by their areas first before interpolation. Stepwise regression were rerun using the adjusted APE as dependent variable. The resulting multiple R's increase substantially in all cases and for both the overlay and the pycnophylactic methods, though the relationship still remains fairly unstable.

In short, the above analysis has demonstrated that there is only a moderate and an unstable relationship between the accuracy of the target zone estimates and the error factors as defined. The second analysis suggests that further improvement on the model could be made in several ways. First of all, the definitions of the variables could be modified. The higher R's obtained from using the adjusted APE is one example. Secondly, different forms of the model may also be used instead of the linear one. For example, although a higher number of split source zones may likely include a larger amount of error, it is also expected that if these split source zones occupy only a small portion of the target zone area, then the error will likely be smaller. So these two factors could compensate each other and in mathematical form they should multiply each other instead of as two independent variables. In addition, the effect of the number of split source zones on the estimation error may also be reduced if most of the split zones are homogeneous. Again, these two factors could compensate each other by multiplication. Finally, different sizes and shapes of source and target zones could be used to encompass a wider range of values in the variables of the number and the area of split source zones.

CONCLUSION

This paper has illustrated that for every target zone estimate resulted from using the overlay and the pycnophylactic methods, there is a theoretical maximum error range, which is a major characteristic of the volume-preserving areal interpolation methods. In estimating the error within the range, several factors are suggested. They include the number and the area of split source zones and the variation in values of neighboring zones. The initial analysis has indicated that a moderate to weak linear relationship exists between the estimation error and the selected factors. However, redefinition of the error variable has improved the relationship substantially. It is suggested, therefore, that improvement of the model could be made in future studies by modifying the form of the model and the definitions of the variables.

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MEASURING THE FRACTAL DIMENSIONS OF EMPIRICAL CARTOGRAPHIC CURVES

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Abstract

The fractal dimension of a curve is a measure of its geometric complexity and can be any non-integer value between 1 and 2 depending upon the curve's level of complexity. This paper discusses an algorithm, which simulates walking a pair of dividers along a curve, used to calculate the fractal dimensions of curves. It also discusses the choice of chord length and the number of solution steps used in computing fracticality. Results demonstrate the algorithm to be stable and that a curve's fractal dimension can be closely approximated. Potential applications for this technique include a new means for curvilinear data compression, description of planimetric feature boundary texture for improved realism in scene generation and possible two-dimensional extension for description of surface feature textures.

INTRODUCTION

The problem of describing the forms of curves has vexed researchers over the years. For example, a coastline is neither straight, nor circular, nor elliptic and therefore Euclidean lines cannot adquately describe most real world linear features. Imagine attempting to describe the boundaries of clouds or outlines of complicated coastlines in terms of classical geometry. An intriguing concept proposed by Mandelbrot (1967, 1977) is to use fractals to fill the void caused by the absence of suitable geometric representations. A fractal characterizes curves and surfaces in terms of their complexity by treating dimension as a continuum. Normally, dimension is an integer number (1 for curves, 2 for areas, and 3 for volumes); however, fractal dimensions may vary anywhere between 1 and 2 for a curve and 2 and 3 for a surface depending upon the irregularity of the form. Although individual fractals have been around since the 1900's, Mandelbrot was the first to recognize their applications outside of mathematics.

This paper discusses an algorithm, written in an interactive setting, designed to measure the fracticality of a curve and additions to theory. It also presents results from examining several cartographic curves.

DEFINITION OF FRACTALS AND SELF-SIMILARITY

In Euclidean geometry every curve has a dimension of 1 and every plane has a dimension of 2. This is generally referred to as the topological dimension (Dt). These dimensions remain constant no matter how complex or irregular a curve or plane may be. For example, the west coast of Great Britain contains many irregularities, but the topological dimension remains 1.

In the fractal domain a curve's dimension may be between 1 and 2 according to its complexity. The more contorted a straight line becomes, the higher its fractal dimension. Similarly, a plane's dimension may be a non-integer value between 2 and 3. The fractal dimension for any curve or surface is denoted by (D) and within this framework: $D \geq Dt$. Mandelbrot (1977) proposes the following definition for a fractal: "A fractal will be defined as a set for which the Hausdorff-Besicovitch dimension strictly exceeds the topological dimension." The precise definition of the Hausdorff-Besicovitch dimension can be found in Besicovitch and Ursell (1937).

Central to the concept of fractals is the notion of self-similarity. Self-similarity means that for any curve or surface a portion of the curve or surface can be considered a reduced image of the whole. However, seldom in nature (crystals are one exception) does self-similarity occur and therefore a statistical form of self-similarity is often encountered. In other words, if a curve or surface is examined at any scale it will resemble the whole in a statistical sense; therfore, D will remain constant. Brownian motion is an excellent example of statistical self-similarity. Because of this principle, a curve can be decomposed into $N=r$ nonoverlapping parts and each subsegment has a length of $1/r=1/N$. Similarly, a unit square can be divided into $N=r^2$ squares, where the similarity ratio is $r(N) = 1/r = 1/N^{1/2}$. In either case the following equation applies:

$$D= \log N/\log (1/r) \quad (1)$$

and could be called the shape's similarity dimension. D can also be expressed as:

$$D=\log (N/N_0)/\log (\lambda_0/\lambda) \quad (2)$$

where λ_0 and λ are two sampling intervals and N_0 and N are the number of such intervals contained. If a curve resembles a straight line then when the sampling interval is halved, N doubles and the proportion equals 1. The majority of cartographic curves are not straight lines and therefore N will more than double causing D to be greater than 1. The principle of self-similarity is dismissed by Goodchild (1980), Hakanson (1978), and Scheidegger (1970). Hakanson, for example, points out the absurdity of postulating the validity of self-similarity down to the size of the pebbles on the coastline and at the molecular interstices of those pebbles. Goodchild demonstrates that although Richardson (1961) found the west coast of Britian to have a constant D of 1.25 over sampling intervals between 10 and 1000km., he found the east coast to vary between 1.15 and 1.31 for a similar sampling interval. This suggests that whatever created the irregularities on the coastline acted at specific scales. Goodchild states that since self-similarity is only one aspect of the fractal approach, it would be unwise to reject the entire concept.

DEVELOPMENT OF THE FRACTAL CURVE ALGORITHM AND EXTENSION OF THEORY

The following original algorithm is based on the earlier empirical work performed by Richardson (1961) and later extended by Mandelbrot (1967). Richardson measured the lengths of several frontiers by manually walking a pair of dividers along the outline so as to count the number of steps. The opening of the dividers (n) was fixed in advance and a fractional side was estimated at the end of the walk. The main purpose in this section of Richardson's research was to study the broad variation of Σn with n.

Richardson produced a scatterplot in which he plotted log total length against log step size for five land frontiers and a circle. Mandelbrot (1967) discovered a relationship between the slope (β) of the lines and fractal dimension (D). To Richardson the slope had no theoritical meaning, but to Mandelbrot it could be used as an estimate of 1-D, which leads to:

$$D=1-\beta \tag{3}$$

The algorithm simulates walking a pair of dividers along a curve and counts the number of steps. In cases where more than one intersection occurs, the intersection which comes first in order forward along the curve is selected. To be more accurate, step size (prescribed opening of the dividers) is called chord length (cl) and the number of steps is called the number of chord lengths.

In order to begin walking the dividers along the curve, the dividers must be set to some opening. The curves used in this research are not infinitely subdivided fractal curves so that selection of the initial chord length must be based on some attribute of the curve. For a very contorted curve it would be meaningless to choose a chord length many times shorter than the shortest line segment. If an extremely short chord length is selected, an attempt to examine the fractal character of a curve would extend beyond the primitive subelements used to represent the geometry of the resulting form. In other words, beyond this lower limit of primitive subelements, the curve's fractal dimension behaves as if it is a straight line. A suggested initial chord length is determined by calculating the distance between each two consecutive points on the curve and taking 1/2 the average distance. The average distance is divided by 2 because the sampling theorem states one should sample at 1/2 the wavelength so that no significant variation escapes. This presents an approximate lower limit as to the selection of the initial chord length. Although the accuracy of this method is dependent on the manner in which the curve is digitized, the form of the curve often dictates this manner.

After the initial chord length is determined, the algorithm computes the distance between the first two points on the curve using the standard distance formula. If the distance is greater than chord length (cl), a new point is interpolated between points 1 and 2 using the following interpolation equations:

$$DP = (cl\text{-}DIST1) / (DIST1\text{-}DISTA) \tag{4}$$

$$XNEW = X_1 + DP*(X_2-X_1) \tag{5}$$

$$YNEW = Y_1 + DP*(Y_2-Y_1) \tag{6}$$

where DP = distance proportion
DIST1 = distance between the present point and the first forward point on the curve
DISTA = distance between the present point and the second forward point on the curve

XNEW = new X- coordinate
YNEW = new Y- coordinate
X,Y = X and Y coordinates of point 1 and 2.

Figure 1 demonstrates how a point is interpolated on a straight line segment.

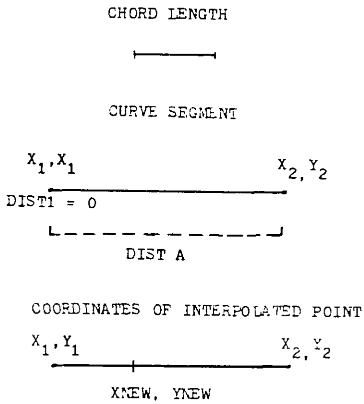

Figure 1. Interpolating on a straight line segment.

If the distance is less than the chord length, the distance between points 1 and 3 (DISTC) is computed. If DISTC is greater than the chord length, it is known that the chord length segment intersects between points 2 and 3 and that the distance between these points is determined (DISTB); See Figure 2a.

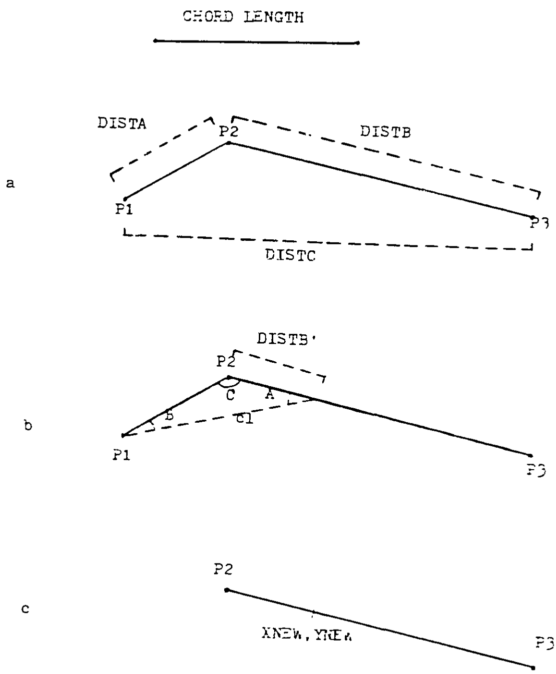

Figure 2. Three point interpolation.

The point of intersection is computed using trigonometric functions. An angle C is determined using the law of cosines.

$$C = \cos^{-1} \frac{DISTB^2 + DISTA^2 - DISTC^2}{2 * DISTB * DISTA} \quad (7)$$

Since angle C is known, an angle A, which is the angle the chord length intersects between points 2 and 3, can be computed.

$$A = SIN^{-1} ((DISTA * \sin C)/cl) \quad (8)$$

Now that two angles are known, angle B is easily computed. Because angles A and B are known, a side (DISTB') can be calculated; see Figure 2b.

$$DISTB' = (DISTA * \sin B)/\sin A \quad (9)$$

DISTB' provides the distance, from point 2, in which the chord length's intersection is located on the segment between points 2 and 3. A distance proportion is calculated using:

$$DP = DISTB'/DISTB \quad (10)$$

Since the distance proportion and the X,Y coordinates for points 2 and 3 are known, the equations used to interpolate for a straight line segment can be used to determine the new coordinates: see Figure 2c. After the new point is located, this new point becomes point 1 and the next two forward points on the curve become points 2 and 3. Each time a chord length's intersection is determined, 1 is added to the number of chord lengths.

In the case where DISTC is less than the chord length, the third point is incremented by 1 (fourth point) and the distance again checked. This continues until the distance is greater than the chord length or the end of the curve is encountered; see Figure 3.

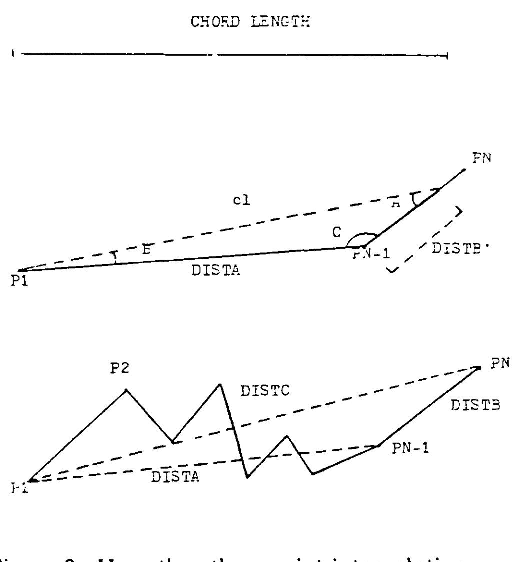

Figure 3. More than three point interpolation.

When the distance does become greater than the chord length, the chord length's point of intersection is determined by using the same trigonometric equations as discussed above. The only difference is the sides of the triangles may be longer. At the end of the curve, if the chord length is greater than DISTA, the portion of the remaining chord length is added to the number of chord lengths.

After the dividers are walked along the curve with the initial chord length, the dividers are opened to another distance. This distance is a geometric adding of the first chord length. For example, if the initial chord length is 2, then the subsequent chord lengths would be 4, 8, 16, 32, 64, and so on. This eliminates biasing when using linear regression because on a logarithmic scale, geometric adding provides equal spacing between the chord lengths.

The number of solution steps or the number of times the dividers, with different chord lengths, are walked along the curve is limited by the number of chord lengths used to estimate length. The minimum number of chord lengths used to approximate length is 5. This is chosen to provide consistency among results as opposed to using a variable limit, but is subject to change pending additional research.

After each time the dividers are walked along the curve, the number of chord lengths and the corresponding chord lengths are saved. These are used in the linear regression where log line length (number of chord lengths *chord length) is regressed against log chord length. A curve's fractal dimension is determined by using equation 3.

To provide an indication of the proportion of variance in the response variable explained by the describing variable, r^2 is computed. This value plays an important role in determining the optimum number of solution steps. A low r^2, for example when the number of solution steps equals 12, means the initial chord length falls below the primitive subelements. A low r^2 is determined by decreasing the number of solution steps and comparing the two values. The desirable number of solution steps is indicated when r^2 reaches its maximum without the number of steps falling below 5. A linear regression with less than 5 points opens up some criticisms as to the validity of results and it should be emphasized the linear regression is used as a parameter estimate and not for statistical inferences.

EXAMPLES AND RESULTS

Of the five land-frontiers Richardson measured, four have been point digitized and used in this study. They are: coast of the Australian mainland; coast of South Africa, starting from Swakopmund to Cape Sta. Lucia; frontier between Spain and Portugal, moving south to north; and the west coast of Great Britain, from Land's End to Duncansby Head. Table 1 shows D as the result of Richardson's measurements and the new D suggested by this research. The expected discrepancy is the result of the digitization process because digitization allows the capture of minute detail in a curve, and since these curves were digitized at a larger scale, a higher D is anticipated.

Curve	Slope (β)	D (1-β)	New D
West Coast of Great Britain	-.25	1.25	1.2671
Coast of Australia	-.13	1.13	1.1490
Coast of South Africa	-.02	1.02	1.0356
Land-frontier between Spain and Portugal	-.14	1.14	1.1014

Table 1. Result from Richardson's (1961) research, corresponding fractal dimension and the new suggested fractal dimension.

For this paper, Kodiak Island is used to demonstrate how the fractal curve algorithm operates. The curve was digitized in trace mode with delta minimum and delta maximum variations at .002 and .05 respectively. The outline contains 1653 points and is in Figure 4.

Figure 4. Kodiak Island with 1653 points where the fractal dimension equals 1.3105.

The results from calculating D are in Table 2 where the different initial chord lengths are selected to show the possible variations in D over a number of sampling intervals. The results show D to vary from 1.1836 to 1.3714. These variations in D reflect a lack of self-similarity in the curve.

Initial Chord Length	D	R-SQ	No. of Solution Steps
.00400	1.1836	.827614	10
* .01833	1.2619	.916728	8
** .03666	1.3025	.954146	7
.05894	1.3105	.976810	6
.07500	1.3466	.964087	6
.08000	1.3660	.972126	6
.10000	1.3714	.975220	5

*Suggested initial chord length
**Average segment length

TABLE 2.
Kodiak Island at 1:1,000,000 with 1653 points

The selection of an extremely short initial chord length of .01833 represents examining the curve below its primitive subelements and biases D toward a straight line. The corresponding scatterplot in Figure 5 displays a curvature of the data points resulting in a lower R-SQ.

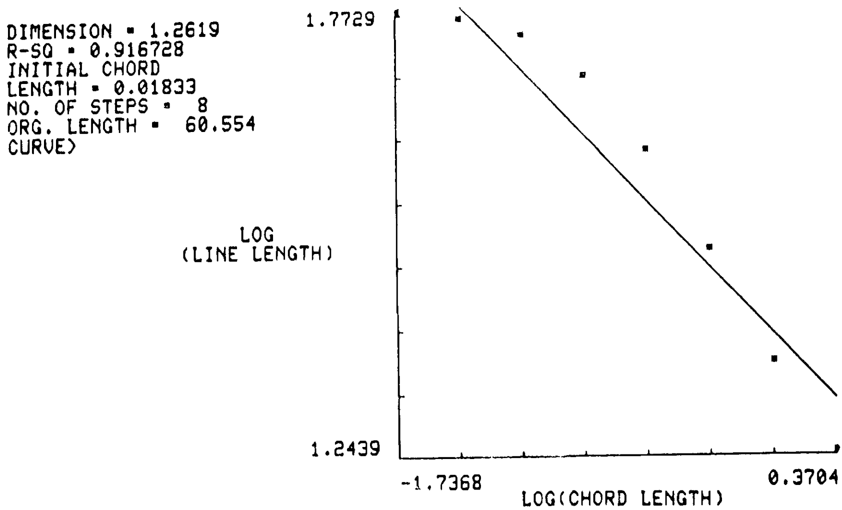

Figure 5. Scatterplot for Kodiak Island (1653 points) where the initial chord length equals .01833.

It is this type of curvature, resembling the shape of a rainbow, that indicates the shortness of the chord length. The chord length of .01833 is the average segment length and is calculated by computing the distance between each two consecutive points on the curve, summing the distances, and dividing by the number of segments. The suggested D to represent the curve is 1.3105. The most appropriate D value is determined from the minimum amount of curvature present in the scatterplot resulting in the relatively high R-SQ value. The suggested initial chord length of .03666 is still too small, indicated by the low R-SQ value, but represents a starting point at which to determine D.

A thinned version of Kodiak Island is in Figure 6 and contains 1000 points.

Figure 6. Kodiak Island with 1000 points where the fractal dimension equals 1.2949.

The elimination of 653 points is accomplished with a program which deletes excessive points within a certain chord length. Table 3 indicates D varying between 1.214 and 1.3659.

Initial Chord Length	D	R-SQ	No. of Solution Steps
.00700	1.1778	.861745	9
.00800	1.2144	.867113	9
* .02947	1.2558	.942722	7
** .05894	1.2949	.974398	6
.10000	1.3659	.971356	5

*Suggested initial chord length
**Average segment length

TABLE 3.
Kodiak Island at 1:1,000,000 with 1000 points

The comparison between the same chord length of .05894 for the original and thinned islands displays how stable the algorithm is to measure D. This initial chord length produced a D of 1.3105 (1653 points) and 1.2949 (1000 points) giving a 1.19% difference. The D for the 1000 point island is expected to be slightly lower because any data thinning process normally removes some complexity from the feature. The proposed D for the thinned island is approximately 1.2949 and the scatterplot is in Figure 7.

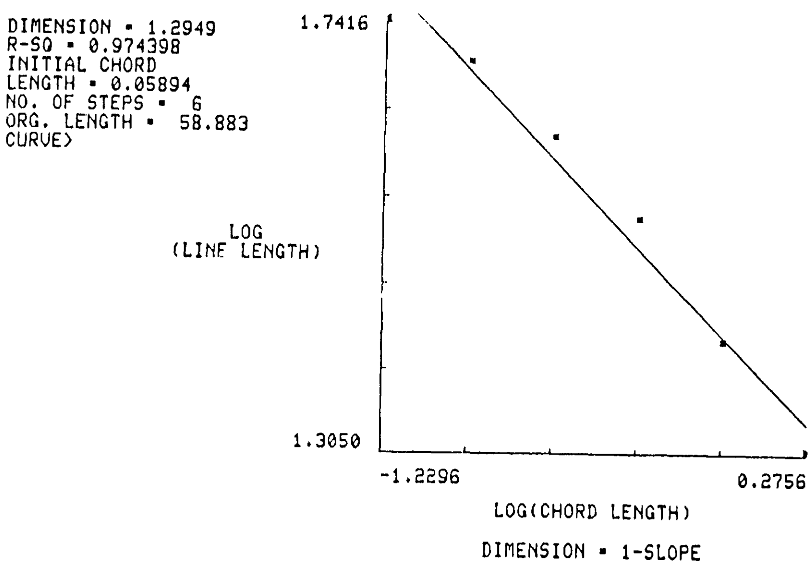

Figure 7. Scatterplot for Kodiak Island (1000 points) where the initial chord length equals .05894.

SUMMARY AND CONCLUSIONS

The results based on the previous empirical curves point out the importance of selecting the appropriate initial chord length. A chord length which is too short is easily detected by either examining the amount of curvature present in the scatterplot or the low R-SQ value. Normally, the suggested initial chord length falls within this category, but it must be emphasized that this chord length is merely a beginning point. The ideal initial chord length, which produces the most appropriate D, is selected by observing the behavior of the scatterplots, R-SQ values, and the number of solution steps. This research, like Richardson's work, indicates that from 5 to 8 solution steps are sufficient to determine the slope of the regression line and thus fracticality.

The results also indicate the fractal curve algorithm to be stable, and that it is able to closely approximate D. The variations in D, over a number of sampling intervals, reflect a need to examine the effects of self-similarity, or lack of it on a curve's fracticality. Finally, this research brings into focus the strong problem solving capabilities, at the hands of cartographers, through the use of interactive computer graphics.

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GEOGRAPHIC AREAS AND COMPUTER FILES FROM THE 1980 DECENNIAL CENSUS

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ABSTRACT

For the 1980 Decennial Census, the United States Bureau of the Census produced two major types of computer files to document the geographic information related to the map sheets used for the census. For areas where GBF/DIME-Files were prepared, these files document the name of every street and other physical feature on the map, along with the address ranges and block numbers pertaining to both sides of each street segment. These files also have latitude and longitude values assigned to each street intersection. The Master Reference File documents the interrelationship of census political and statistical geography, such as census tracts, places, townships, counties, urbanized areas, and so forth. Work is underway to add latitude and longitude values to the centroid location of each major tabulation area. In addition, the Bureau has produced a digital file documenting the boundaries of every county and county equivalent in the United States as of January 1, 1980.

INTRODUCTION

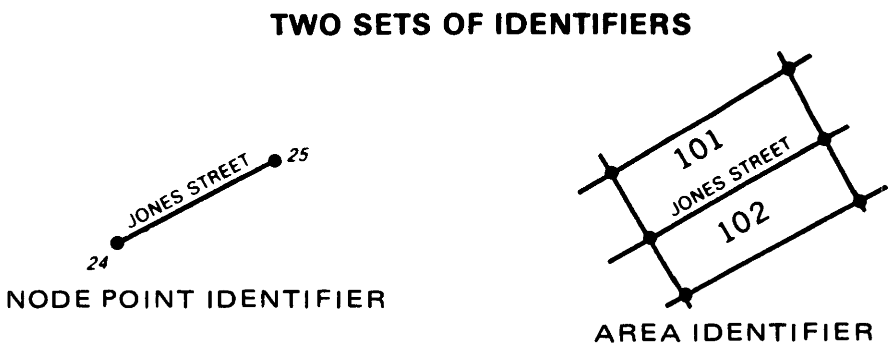
For the 1980 Census of Population and Housing, two computer files were developed, which enable a user to assign geographic location codes to an address. These files are the GBF/DIME-File and the Master Reference File (MRF).

These files were not developed for the purpose of computer-assisted mapping; rather, they were developed to accomplish the task of assigning the correct census geography to a questionnaire enabling the Bureau to tabulate data for the required political and statistical units, such as county, city, or census tract. As a post-census operation, earth coordinates are being inserted into the GBF/DIME-Files, thereby enabling the user to produce maps in a computer-assisted fashion. A version of the MRF available to the public, called the 1980 Master Area Reference File (MARF), will be available as MARF II and have coordinate values for centroids of major tabulation areas. In addition to these two files and as a by-product of the county area measurement project for the census, a new county boundary file also is available and replaces the 1970 county boundary (DIMECO) file.

THE GBF/DIME-FILE

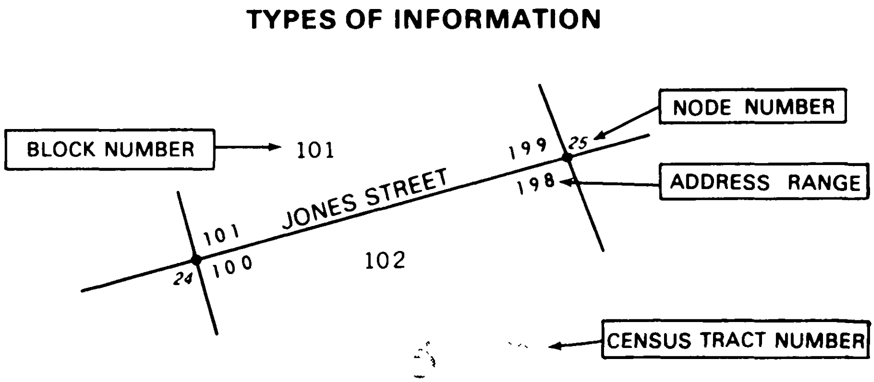
The GBF/DIME System consists of the GBF/DIME-File, a working set of the Census Bureau's Metropolitan Map Series known as the CUE maps, and a computer program to create and maintain the file. The GBF/DIME-File itself is a computerized representation of the CUE map; within the area covered by the file, it contains all features shown on the CUE map plus potential address ranges and ZIP codes for all streets. The file structure is based on graph theory. Each feature on the map is considered a series of lines, and each feature intersection is considered a point (node). An entire map sheet is viewed as a series of interrelated nodes and segments; when connected they create enclosed areas (blocks). This approach is referred to as DIME (Dual Independent Map Encoding). DIME refers to the fact that the computer file which represents the map is created from two independent sets of identifiers for each segment: (1) the node points for each intersection, and (2) the enclosed areas separated by each segment. In Figure 1, a segment of Jones Street may be identified either as that segment between nodes 24 and 25, or as the segment which separates blocks 101 and 102.

Figure 1. A line Segment with DIME Identifiers



Each computer record in the GBF/DIME-File identifies a single segment of a feature between two node points and includes all of the geographic information related to that segment. A feature on the map is divided into a series of segments (computer records) where it intersects with other features, or for the purpose of indicating curvature (curves are represented as a series of straight lines). Each address range is tied to the proper area (block). If the potential address ranges along a blockside are added to a traditional map, the same segment of Jones Street would appear as shown in Figure 2.

Figure 2. A DIME Segment with Address Information

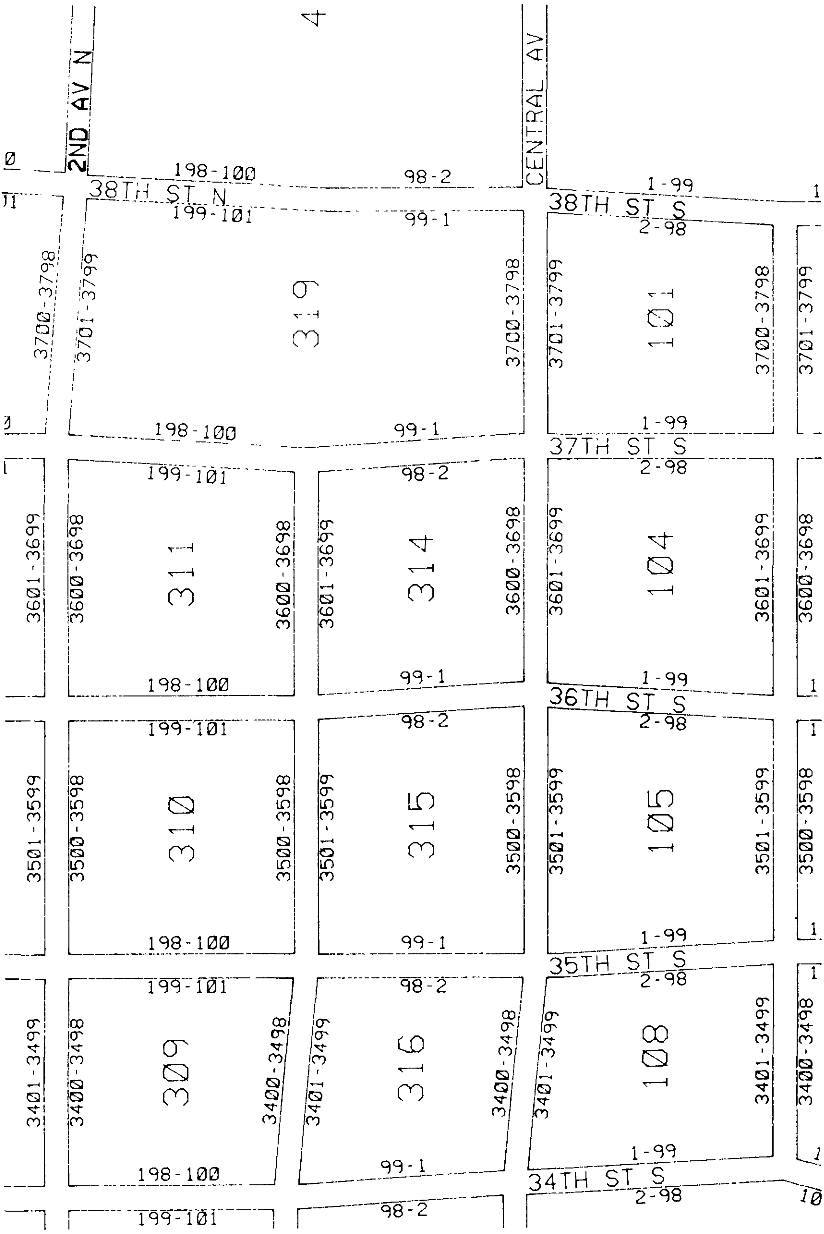


For each segment side, the 1980 GBF/DIME-Files contain the numeric identifiers for state, county, minor civil division, place, census tract and block, the potential address range, and ZIP code. The GBF/DIME-Files were developed to permit the automated assignment of geographic codes to an address without reference to a printed map. The geographic area covered by each file varies by SMSA, but generally the coverage includes the central city and immediate suburbs. These files exist for the 277 Standard Metropolitan Statistical Areas (SMSAs) established by the Office of Management and Budget by 1977 (except in Puerto Rico). Work is now proceeding to create similar files for SMSAs established as a result of the 1980 census. As the GBF/DIME-File is a computer representation of a map, the addition of coordinate values to each node point permits the computer to use the file to display the map. As a post-census operation, each node point is being digitized and the latitude-longitude value inserted into the file. State plane coordinate values are calculated from the latitude-longitude and also inserted into the file. During the digitizing operation, computer plots of each map sheet are reviewed. A completed plot of the Elmira, New York GBF/DIME-File appears in Figure 3. This plot is a mosaic of parts of five map sheets made from page-size copies of the graphics terminal display.

The structure of the GBF/DIME-File enables it to be used in a variety of computer-assisted mapping applications. As the next paper will indicate, the files can become the nucleus for an automated geographic system. The maps produced by the files are accurate only for use in showing feature relationships and not for engineering-type application as the computer can only reproduce a map of the quality that was put into computer-readable form. The Bureau has experimented with using GBF/DIME-Files to produce maps which may be used by a field enumerator in the 1990 census. Automating map production would give the Bureau the capability to produce a map at the proper scale for each enumerator assignment as well as for publication. An experimental map made from a GBF/DIME-File

Figure 3. Elmira, New York GBF/DIME-File

Figure 4. Experimental Field Map



is presented in Figure 4. In lieu of the simple single-line plot shown in Figure 3, the computer has turned each segment into a double-lined street, added feature names, and the potential address ranges. This work is still in the experimental phase, but it clearly shows that computer-drawn maps can simplify the cartographic requirements for 1990.

The fact that the GBF/DIME-File enables a user to assign geographic location codes to local data based on an address, such as police and fire calls, health visits, and so forth, also means that the file can be used to plot the approximate location of an address along a street or determine an approximate coordinate value for the address, assuming linear interpolation of the address range along the street. Combining an address list with the double-line map opens the door to additional use by the Bureau, when one considers that over 325,000 individual ED maps were prepared for the 1980 census. These ED maps were made from over 32,000 1980 Census Map sheets of the type discussed in the first paper, and often required photographic enlargement to meet the various enumerators' requirements. The amount of time and clerical involvement can be substantially reduced for areas covered by GBF/DIME-Files using computer-drawn maps of the type shown in Figure 4.

THE MASTER REFERENCE FILE

The Master Reference File (MRF) was created prior to the 1980 census and was corrected and revised throughout the taking and tabulation of the census. Its purpose is to link all state, county, minor civil division (MCD) or census county division (CCD), and place names with their numeric codes, to indicate the hierarchical relationships between these units and all other political and statistical units, such as census tract, census block, and urbanized area, and to identify the lowest level of geographical code combination which must be tabulated. This smallest geographic area that must be used in tabulation is called a Geographic Tabulation Unit Base (GTUB). Within each GTUB, one or more enumeration districts (EDs) are defined. Associated with each ED are the census blocks or block portions (in block numbered areas) covered by the ED. In the public files, EDs are replaced by block groups (where blocks exist) for tabulation purposes. Census tract (or block numbering area (BNA)) is an inseparable corollary to each census block. The combination of tract (BNA)/block relates to other levels of geography. In unblocked areas, EDs (without relation to census tract) served this function. Even in block number numbered areas, the ED was the basic unit for enumeration.

A section of an MRF might appear as shown in Table 1, where the "R" column indicates the geographic level. A code of all "9's" indicates that the geographic level contains more than one code for the specified type of activity, or has area territory inside and outside the geographic area.

TABLE 1

R	ST	CO	MCD	PL	TRACT	CD	UA	NAME
S	51					99	9999	VIRGINIA
C	51	001				01		ACCOMACK
M	51	001	005			01		ATLANTIC
P	51	001	005	0580		01		HALLWOOD
T	51	001	005	0580	9903	01		
G	51	001	005	0580	9903	01		
E	51	001	005	0580	9903	01		ED 56 BL 106 107 108 109 110 111 112 113
P	51	001	005	1100		01		SAXIS
T	51	001	005	1100	9903	01		
G	51	001	005	1100	9903	01		
E	51	001	005	1100	9903	01		ED 57 BL 201 202 203 204
E	51	001	005	1100	9903	01		ED 58 BL 301 302 303 304

From this example, geographic interrelationships are illustrated. For example, BNA 9903 appears in at least two places, Hallwood and Saxis. The 100 block group (BG) is in Hallwood and the 200 and 300 block groups are in Saxis. (A block group is that set of blocks within a census tract sharing the same first digit.) Both Hallwood and Saxis are in Atlantic MCD which is in Accomack County, Virginia. Other codes in the MRF would indicate that Atlantic is an MCD and not a CCD, and that Hallwood is an incorporated place while Saxis is a Census Designated Place (CDP). All political boundaries represented in the MRF are as of January 1, 1980 as reported to the Bureau.

The MRF was clerically constructed from the 1980 Census Maps. All of the required boundaries were plotted and the smallest unit required for tabulation (GTUB) was determined. EDs were defined within GTUBs, first on the maps and then translated to the MRF. A public version of the MRF is called the 1980 Master Area Reference File (MARF) and contains 1980 population and housing counts. It does not contain GTUBs, EDs within block numbered areas, or block numbers. In block numbered areas, it contains a record for each block group (BG). The 1970 equivalent of the MARF is known as the MEDList, a version of which (MEDList-X) contains coordinate values for the approximate population centroids of each ED. For 1980, a second version of the MARF (MARF II) will contain the approximate population centroid of each ED or BG. (Budget constraints had eliminated MARF II as a 1980 census product. Current indications are that MARF II will be reinstated.)

When MARF II becomes available, the user will have a nationwide tool which can be used to graphically display and analyze census data. Although MARF II will only give the user a single set of coordinate values for an ED or BG, that will be sufficient in most cases to make close approximations of the population within a specified distance of a desired location. Combined with the digital county boundary file, which can be used to plot the county boundary, a user will be able to display census data available by ED/BG assuming the ED/BG extends half-way to the next centroid or to the county boundary. This is only one example of what users may do with MARF II provided they develop the necessary software.

CAVEATS

The GBF/DIME-Files were created or updated for the most part during 1976 through 1978, and at best represent 1977 vintage on the ground features, political and statistical geography, address information, and ZIP codes. Over 300 local agencies worked on this project and were responsible for content and geographic extent of the files. At the tract/block level, agreement between the CUE maps (and GBF/DIME-Files) and the 1980 census publication maps (as published in the block statistics reports) is about 98 percent for all GBF/DIME-File areas. For any single file, the rate of disagreement between the tract and block numbers could be as high as 7 percent. Reference has been made to CUE maps, which are not the same as the 1980 Census Maps or 1980 Metropolitan Map Series (MMS). CUE maps are copies of the working maps used by local agencies to create or update the GBF/DIME-Files and are the only set of maps that contain node numbers. As they were the basis for the update of the artwork used to produce the 1980 Census Maps, differences occurred because of the clerical nature of the work and census requirements. Because the GBF/DIME-Files predate the census, no geographic codes other than the tract and block numbers should be used when matching to census data. With the exception of the New York, NY SMSA, tract numbers are unique within an SMSA and can be used as a match key to the MARF to obtain any other geographic codes required. In the New York, NY SMSA, tract numbers are unique within county.

The MRF, which is also the basis for geographic codes in all of the 1980 census Summary Tape Files (STFs) available to the public, also was created through a clerical process and prone to clerical error. Users will sometimes find a block number (available in STF 1B and report PHC80-1) which does not appear on the 1980 Census Map, or vice versa. The number of these occurrences is very small nationwide, but the user attempting to match the MARF/STF, 1980 Census Map, and GBF/DIME-File must be aware that there may be some cases in which these three sources will be inconsistent.

The digital county boundary file is distributed in a new file structure, called the Geographically Encoded String Structure (GESS). The GESS is easy to convert to both polygons and segments and can be reformatted into a DIMECO type file.

CHOROPLETH MAP ACCURACY: CHARACTERISTICS OF THE DATA

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ABSTRACT

The accuracy of maps based on aggregate data is dependent upon (a) the extent to which aggregate values calculated for each enumeration unit are representative of the entire unit and, (b) the data classification system used to assign these values to classes. Size and compactness of these units as well as the variability of the distribution mapped are important factors in determining the accuracy of aggregate values calculated for the units. In this study, the individual and relative importance of these enumeration unit and surface characteristics are examined. Analysis indicates that all three variables exert a significant influence on accuracy of aggregate values with surface variation accounting for the greatest portion of the variation in accuracy.

INTRODUCTION

In contrast to the considerable attention directed toward the accuracy with which choropleth maps communicate spatial information, little attention has been given to the accuracy of the maps themselves. With the advent of geographic information systems and the concomitant development of interactive choropleth mapping capabilities such as the Domestic Information Display System and the SASGRAPH package, choropleth maps are becoming increasingly important in planning and decision making. For maps to be effectively and appropriately used in this context, it is necessary that accuracy of these maps be carefully considered.

Choropleth map accuracy is, to a large degree, a function of methods by which data are organized. Data for choropleth maps consist of aggregate values for enumeration units such as states, counties, or census tracts. An underlying assumption of the choropleth technique is that data within each unit are of equal value and evenly distributed across the unit. For choropleth maps, then, accuracy will be a function of (a) the variation of data within each unit from the aggregate value representing that unit and, (b) the data classification system used to assign values to classes.

While the effect of data classification procedures on the accuracy with which aggregate values are represented has been considered (Jenks and Caspall, 1971 and Monmonier, 1982), the influence of data characteristics and organization procedures on aggregate value accuracy has been largely ignored. One explanation for a lack of attention to accuracy of the data may be a perceived inability to manipulate the variables involved. While cartographers can control shading patterns or data classification procedures on a choropleth map, they have little or no ability to control size and shape of enumeration units or the nature of the distribution mapped.

Whether or not the cartographer can control all variables, a responsibility exists to evaluate the potential for error on maps produced. In some cases this evaluation may result in a decision that the available aggregate data will not produce a sufficiently accurate map or that an alternative to a choropleth map should be used. In other cases, when it is decided that the map is to be constructed, map users could be provided with a measure of overall map accuracy or alerted to regions of the map where, due to questionable data, caution should be taken in interpretation.

As a step toward development of a method for determining the potential for error of individual choropleth maps, the focus of the present study is on the correspondence between aggregate values and the data they represent. It is postulated that three factors: enumeration unit size, enumeration unit compactness, and variability of the data distribution, are the determinants of aggregate value accuracy. Variability of the data distribution is expected to be indicative of data variation within each unit. Therefore, accuracy will decrease as distribution variability increases.

Size and compactness of units are expected to influence aggregate value accuracy because of their direct correspondence to distances among individual data elements. The larger and less compact the units, the farther apart individual locations within the units will be and, consequently, the more likely it is that their characteristics will vary. Aggregate values representing units, therefore, will decrease in accuracy as size of units increases and as compactness decreases.

Coulson has suggested that size and compactness of units have an equal influence on accuracy of aggregate values. From a theoretical point of view, this is readily apparent. In practice, however, the relative importance of size and compactness will be a function of the variation of each factor for the units involved.

METHODOLOGY

The focus of the present study was on one aspect of choropleth map accuracy -- the accuracy of aggregate values to be mapped. For this purpose, a set of contiguous enumeration units, such as the counties in a state, was not essential. In an effort to obtain an adequate range in size and shape of units, individual rather than contiguous enumeration units were used. The units selected consisted of a stratified random sample of six counties from each of nine regions of the U.S. (Fig. 1a and 1b). The actual units varied in size by a ratio of about 6 to 1 from largest to smallest. For convenience of illustration, however, all units are scaled to the same area.

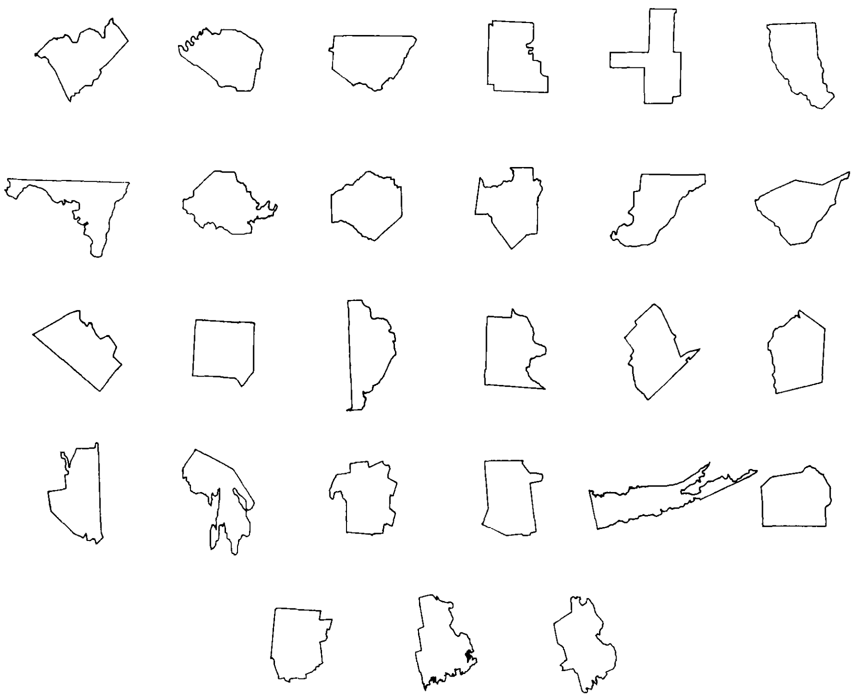


Fig. 1a. Sample Units

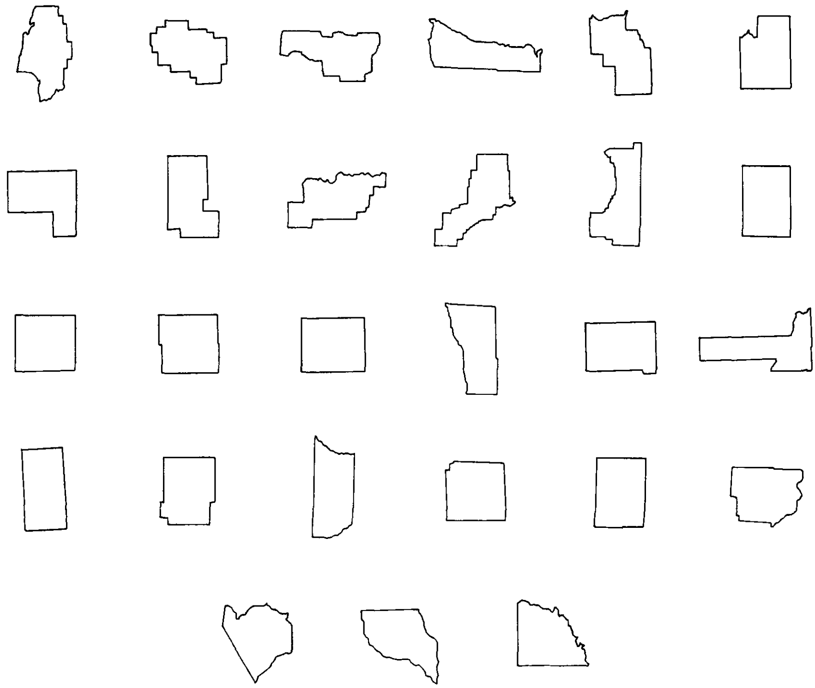


Fig. 1b. Sample Units

For the influence of data distribution variability on aggregate value accuracy to be examined, distributions representing a range in variability were necessary. Four distributions were utilized. The first (Fig. 2a) was a simple linear surface that decreases in value along a diagonal. This was assumed to be the simplest surface. The remaining distributions were derived from actual topographic surfaces and can be described as: a roughly conic surface (Fig. 2b), an undulating linear surface (Fig. 2c), and a highly irregular surface (Fig. 2d). Each surface was generated from a set of control point values by the Surface II Graphics System (Sampson, 1975). This system generates a square grid matrix of z-values from which an isoline map or perspective plot can be created. In this case each matrix consisted of 112 rows and 75 columns 1/10 of an inch apart.

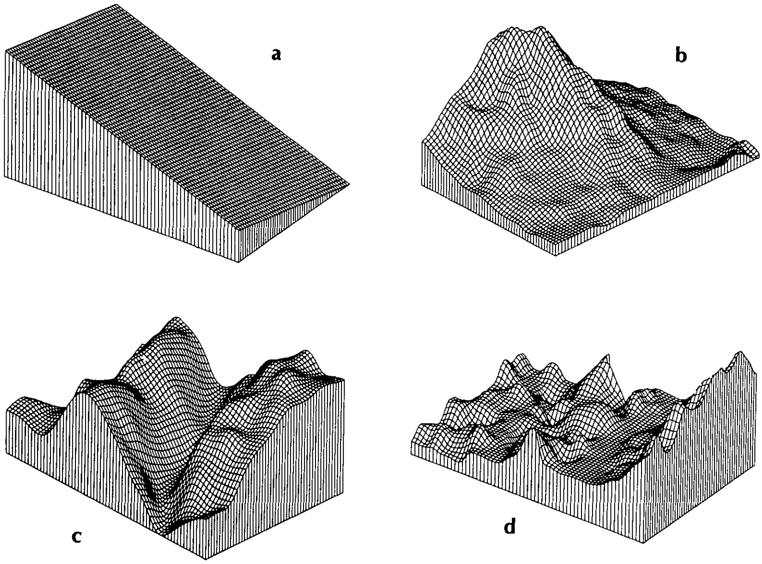


Fig. 2 Sample Surfaces

Measurement of Accuracy

In terms of the choropleth assumption of homogeneity within units, accuracy can be measured as the variance of values occurring within a unit around the mean or aggregate value used to represent that unit. To obtain this measure, each unit was positioned, at a random location and orientation, on the grid matrix representing a distribution. Points of the matrix inside the unit were determined (Fig. 3). There were between 30 and 300 points within each unit depending on its size. The mean and standard deviation of z-values at these points were calculated and the coefficient of variation for the standard deviation was computed. This coefficient of variation was used as the measure of aggregate value accuracy.

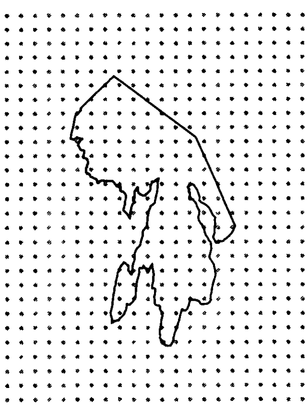
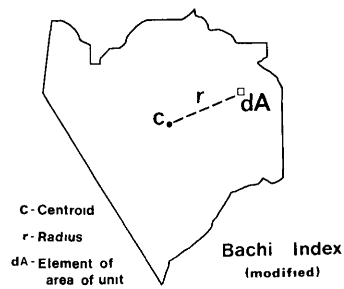


Fig. 3 Sampling of Grid Matrix

Measurement of Variables

A variety of methods have been proposed for the measurement of enumeration unit compactness (Blair and Biss, 1967). While a number of simple measures based on the perimeter or area of the unit exist, the method that, from a theoretical standpoint, should be most accurate deals with the unit as a whole rather than with a single parameter of the unit. Each unit is considered to be composed of a series of infinitesimally small elements of area (Fig. 4). Variation in location of these elements in relation to the unit's centroid is the basis for the measure. It is calculated as the sum of the variance in X and Y locations of the elements, adjusted so that values range from zero to one, the latter being the value for a circle, the most compact shape. Versions of this measure have been presented by Bachi (1973), Blair and Biss (1967), and Coulson (1978). The relative distance standard deviation is the form used here.



$$\text{Relative Distance Variance} = \frac{\text{Area}}{2\pi\ (\sigma_x^2 + \sigma_y^2)}$$

$$\text{Relative Distance Standard Deviation} = \sqrt{\frac{\text{Area}}{2\pi\ (\sigma_x^2 + \sigma_y^2)}}$$

Fig. 4 Compactness Index

While compactness can be compared to the most compact possible shape, there is no single standard to which size can be compared. Any measure of size devised, therefore, is a relative measure; meaningful only in a given context. One practical measure of size is to calculate a ratio between the size of each unit and an arbitrary standard. Convenient standards are the largest, smallest, mean, or median size of units. The largest and smallest units have the advantage of resulting in a scale from zero to one.

Coulson (1978) has advocated the use of the smallest unit as a standard in order to produce a scale comparable to that for compactness. Values would range from zero to one with high values indicating a potentially more accurate aggregate value, as they do for the standard distance deviation scale of compactness. The problem with this approach is that the size ratio is dependent on one, possibly extreme, value.

Although not as easily interpreted, the median size of the set of units will provide a more stable standard and is used here. The median is preferable to the mean because the distribution of enumeration unit size is likely to be highly skewed with a small number of large units that would exert unwarrented influence on the mean.

Surface variability can be measured in a number of ways. An important consideration in selecting a measure is the frequency of variation. For example, a distribution that exhibits extreme variability on a continental scale may exhibit little or no variation across a possible mapping unit (e.g., a county). A measure of data distribution variation that takes mapping unit size into account is requisite.

In the present study, surface variability is measured by comparing neighboring z-values in the grid matrix representing each distribution. The measure used is the spatial autocorrelation of grid z-values at a lag equal to the average longest axis of the units examined. This measure will reflect the maximum likely variation within an average mapping unit.

ANALYSIS

Previous research (MacEachren, 1982) has demonstrated that both size and compactness of enumeration units exhibit the expected influence on aggregate value accuracy. Accuracy increases as size decreases and as compactness increases. The influence of each factor on aggregate value accuracy was shown to be a function of the factor's variation across the units examined; the greater the variation the greater the influence on accuracy.

In the present study, a third factor, data distribution variability is considered. Multiple regression analysis is used to determine the relative influence of unit size, unit compactness, and distribution variability on aggregate value accuracy.

To examine the influence on accuracy of these factors, the accuracy value, the coefficient of variation, is calculated for each of the 54 units positioned on each of the four distributions. Multiple regression of these variation ratios with the measures of unit size, unit compactness, and data distribution variability indicates that all three factors explain a significant portion of the variation in aggregate value accuracy (Table 1).

TABLE 1. MULTIPLE REGRESSION OF ACCURACY WITH SIZE, COMPACTNESS, AND SURFACE VARIATION

Variables	Multiple R	R^2	R^2change	Simple R
Surface variation	.76	.58	.58	.76
Size	.94	.89	.32	.56
Compactness	.97	.93	.04	-.20

Data distribution variability, as measured by spatial auto-correlation, provides the greatest contribution to an explanation of variation in aggregate value accuracy. As expected, with increasing variation at a frequency corresponding to enumeration unit size, there is a decrease in aggregate value accuracy.

For the enumeration units included, size exhibits greater variation than does compactness (Table 2). As expected, therefore, unit size provides the greater contribution toward explaining variation in accuracy. This is evident in both the simple correlation of the variables with accuracy and in their respective contributions to the multiple regression.

TABLE 2. SIZE AND COMPACTNESS COMPARISON

	Mean	S.D.
Square Root of Size Ratio	0.96	0.28
Compactness Index	0.88	0.09

CONCLUSIONS

The specific focus of the present study has been the relative influence on aggregate value accuracy of enumeration unit size, enumeration unit compactness, and data distribution variability. Results indicate that data characteristics have a greater influence on aggregate value accuracy than do characteristics of the enumeration units to which data are assigned. Enumeration unit characteristics, however, have also been shown to be significant factors.

These findings suggest that, while the extent to which data meet choropleth assumptions remains a primary consideration for choosing the choropleth technique, unit size and compactness should be considered as well. It is possible, for example, that while a particular phenomenon is well suited to choropleth representation, the size and compactness of the units to which data are aggregated may produce significant differences in accuracy from one part of the map to another.

Results of the present study are one step toward the overall goal of a method for determining potential error in specific choropleth maps. The importance of both data characteristics and the manner in which data are aggregated have been demonstrated. To produce maps of potential error in specific choropleth maps, however, the relative importance of these variables and data classification procedures must be determined. In addition, a method of estimating data distribution variability from aggregate data when individual data are not available must be derived.

Developments in both hardware and software of computer-assisted cartography are resulting in an increased potential for the use of maps in decision making. It is now possible to produce maps of current information quickly and inexpensively. As thematic maps are increasingly used to make decisions rather than simply illustrate decisions, more careful consideration of their accuracy is essential.

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THE SHL-RAMS SYSTEM FOR NATURAL RESOURCE MANAGEMENT

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BIOGRAPHICAL SKETCH

Robert J. Madill (P. Eng.) received a Bachelor of Electrical Engineering from McGill University in 1970, and a Master of Science in Forestry from the University of Toronto in 1973. He was employed for six years with Environment Canada as a Research Officer responsible for the management of biophysical inventory projects, and the application of mini computer based graphics systems for solving natural resource management problems. In 1979, Mr. Madill joined Systemhouse as a Senior Marketing Consultant responsible for domestic and international marketing of Systemhouse Mapping and Earth Resource Systems. Mr. Madill is also involved in the definition of market requirements for the development of Systemhouse mapping products.

ABSTRACT

A system for natural resource management utilizes modern computing science principles to provide facilities for the formulation, analysis and solution of natural resource management problems. The challenge to system builders such as Systemhouse Ltd, is to look beyond the world of bits and bytes, and to adopt the frame of reference of the natural resource professions. This perspective is essential for the successful acceptance and use of computer based tools.

SHL-RAMS is a computer based system for natural resource mapping and analysis. The system aims to reduce the tedious and repetitive operations, such as drafting and manual numerical analysis, and thereby to increase the time available for creative problem solving and the exercise of judgement. The latter processes are made more efficient by the provision of flexible line mapping, thematic mapping and report generation facilities.

Two applications of SHL-RAMS are reviewed - the mapping and analysis of forest biomass data, and the charting and modeling of ice conditions in Canada's north.

INTRODUCTION

SHL-RAMS is a turnkey mapping and analysis system for use in resource management, land use, socio-economic, general mapping and utility mapping applications. The system is used to prepare a geographic polygon database from which line maps, thematic maps and reports may be produced. Two specific applications of RAMS are discussed:

- o Forestry - the Northern Forest Research Centre in Edmonton, Alberta
- o Ice Charting - the Ice Information Service of Environment Canada in Ottawa, Ontario

FORESTRY

The Northern Forest Research Centre (NFRC) of the Canadian Forestry Service is located in Edmonton, Alberta. Under the auspices of the National Energy From Forests Program (Enfor), NFRC has established a co-operative research program to study the energy available from forests in Saskatchewan, Manitoba, Alberta and the Northwest Territories. One area under investigation is the total quantity of wood matter that a forest now has and will produce in the future. Once this total biomass is determined, scientists will be able to calculate the total energy potential of a forest.

RAMS was installed at the NFRC in March 1982. NFRC scientists will use SHL-RAMS to demonstrate the conversion of conventional forest inventories to a biomass inventory. A forest inventory will be digitized and stored in RAMS, updated by Landsat satellite data, and then converted to a biomass inventory by the application of suitable transformations. Colour thematic maps that show the location and distribution of forest biomass will be produced, in addition to quantitative reports.

The NFRC installation included the interfacing of RAMS to an existing in-house mini computer system. This provided data transfer between the two systems and the sharing of peripherals. Two way data exchange software was also supplied for RAMS and the GIMMS system.

ICE CANADA

Floating ice affects a variety of marine activities, including shipping, off-shore resource exploration, and commercial fishing. It is also a major cause of damage to vessels and equipment, resulting in loss of life and ecological disasters.

To minimize the risk associated with marine activities near floating ice, Ice Central, Environment Canada (ICE Canada) located in Ottawa, Ontario, operates an ice information service. This service provides analysis, forecasting, and charting of ice conditions in Canada's navigable waters. ICE Canada is responsible for providing daily, up-to-date information in chart form by integrating data gathered by satellite, ice reconnaisance aircraft, ship and shore stations. The charts are broadcast by HF radio facsimile to ships and other recording stations, and during winter months, are relayed on Atlantic regional weather facsimile circuits. An ice chart includes information on the positiion of ice edges, concentration boundaries, ice types, floe size, and topographic features.

SHL - RAMS was installed at ICE Canada in April 1982. The system will be used to develop an up-to-date digital ice information database. The databse will be used as input to complex ice models to simulate ice behavior, and to produce current ice charts.

The ice information charts are produced in three series:

- o Daily current ice charts at scales of 1:1,000,000 to 1:2,000,000

- o Weekly composite ice charts at a scale of 1:4,000,000

- o Historical ice charts at a scale of 1:6,250,000

The reference base for the daily production of current ice charts is being digitized from Canada's 1:250,000 National Topographic Series. The ice information will be added as layers onto the reference base. Charts will be updated and distributed on a daily basis as new information is received.

The digital ice information database will also be used as input to complex ice models. Model simulation is intended to compliment ice observation and charting, in order to improve forecasts to maritime clients.

SUMMARY

SHL-RAMS is a resource analysis and general mapping system. This paper has reviewed two diverse applications of RAMS, one in forestry, and one in ice charting. SHL-RAMS minimizes the time and effort required to produce up-to-date maps and reports, through the use of sophisticated graphics display, editing and map production facilities.

AUTOMATING THE GEOGRAPHIC AND CARTOGRAPHIC ASPECTS OF THE 1990 DECENNIAL CENSUS

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ABSTRACT

The mission of the Census Bureau is to provide basic statistics about the people and economy of our Nation to the Congress, the Executive Branch, and the general public. To accomplish this mission, geographic support must be provided to assign each housing unit and business establishment to the correct geographic location, and then classify that location according to the tabulation areas represented in the census or survey. Recording all relevant geographic information about an area in a single computer file will permit the assignment of geographic location codes to households and businesses, provide the ability to generate maps showing the geographic information for field operations and subsequent publication, and provide the geographic structure needed for tabulation of the data to every area whose boundaries have been recorded in the file. The Geography Division of the Census Bureau has developed a long-term plan for building and maintaining this computer file.

INTRODUCTION

The mission of the Census Bureau is to provide basic statistics about the people and economy of our Nation to the Congress, the Executive Branch, and the general public. The successful collection and tabulation of these data are dependent on the availability of a variety of geographic materials and services. These geographic materials and services are all geared toward doing two things: First, assigning housing units and business establishments to a geographic location--a block, and then classifying that block into the full range of geographic areas recognized in the data tabulations of that census or survey.

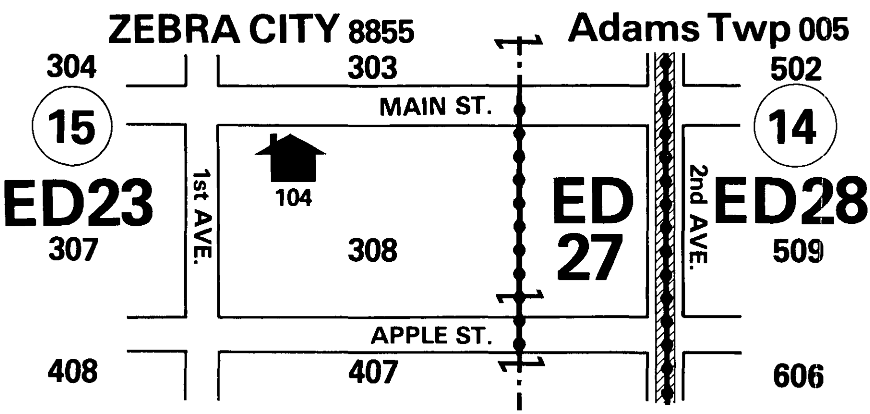
You have heard in the first two papers of this session about the three major tools prepared by the Geography Division to assist the field data collection staff in the completion of their task and the subsequent use of these tools to assist in the tabulation and understanding of these data. You also may have heard from some sources that there were problems with these geographic materials in 1980; problems that caused confusion on the part of the field staff and the data using public.

THE PROBLEM

Understanding what caused the problems with the geographic products in 1980 turned out to be the first major step in planning for the geographic support of the 1990 census. If you think about what you have heard described in the previous two papers, you may recognize that maps, GBF/DIME-Files, and the Master Reference File all have several items in common; that is, they are simply three different ways of describing the surface of the earth.

Maps describe the earth in graphic form showing both the lowest levels--streets, railroads, streams, and the polygons, which we call blocks, delimited by those features. Maps also show the higher level geographic units into which we classify blocks--census tracts, cities, townships, counties, urbanized areas, and so forth. (See Figure 1.) Using this map, a census enumerator can walk around a block, list the addresses seen along each side of the block in a book called an address register, and at the same time record the number of the block containing that address. For example, that 104 Main Street is in block 308. In that simple act of writing down the block number, the enumerator has "geocoded" the address; that is, assigned it to a geographic location. This is how censuses have been taken for the 200 years of America's history.

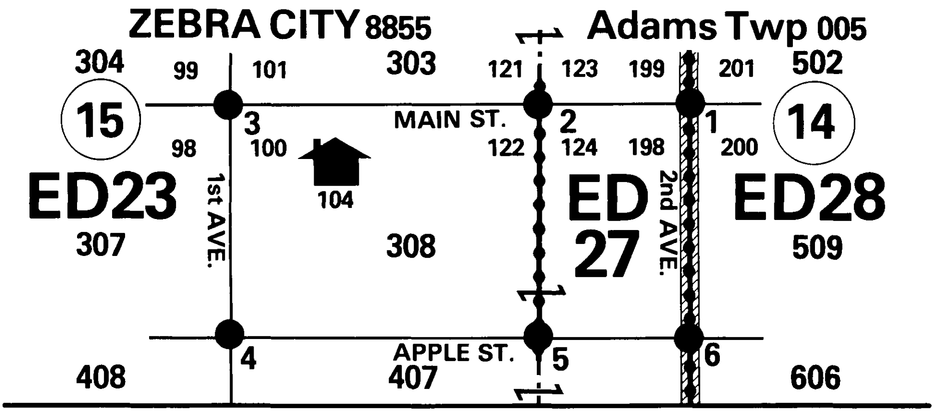
Figure I



The GBF/DIME-Files describe the same lowest levels of geography--streets, railroads, streams, blocks, and census tracts--in a manner that is understandable by a computer. (See Figure 2.) The GBF/DIME-Files add two critical pieces of information to the computer's knowledge of the map.

° First, they record the address ranges that apply to each street segment. This additional information allows the computer to "see" what addresses fit into each block using computer matching algorithms which perform the geocoding function previously done by an enumerator. For example, 104 Main Street "fits" in the range 100-122 on Main Street and is, therefore, in block 308.

Figure 2



Street Name	From	To	Place	Tract	Left Block	Right Block
MAIN ST.	3	2	8855	15	303 101-121	308 100-122
MAIN ST.	2	1	——	15	303 123-199	308 124-198

° Second, they record the geometric description of the map in the form of latitude and longitude values for each intersection (and some intermediate points) shown on the map. These points are called "nodes" and have been assigned numbers for use in linking the coordinate values read from the maps to the computer files. The GBF/DIME-Files can geocode addresses without the coordinates, but they can't drive a plotter unless this information is present.

The Master Reference File describes the same map in a third way--by recording in computer-readable form the relationships of the lowest level geographic area, the block, to all higher level geographic areas for which data will be tabulated. (See Figure 3.) This is done enumeration district-by-enumeration district. For example, this file tells you that ED 23 contains block 308 which is in census tract 15, Zebra City (code 8855), Adams Township (code 005), county 001, state 01, and so forth.

As you can see from this example, we have a problem in the Master Reference File: The place code for Zebra City was written as 8885 instead of 8855. This error in the Master Reference File now causes this file to "mismatch" with the GBF/DIME-File and the maps. In 1980, this type of mismatch caused a cascade of problems in all subsequent geographic products related to Zebra City and resulted in much of the discontent expressed by our field staff and data users.

Figure 3

ED23 01 001 005 8885 15
303P 304 307 308P 407P 408

ED27 01 001 005 —— 15
303P 308P 407P

ED28 01 001 005 —— 14
502 509 606

Now, that we have seen what the products were for 1980 and what kind of problem existed, let's look at the cause of our problems. To create the three products described we used people. One group of people (about 900 of them) drew the maps, named all of the streets they could, plotted all of the boundaries, and rubbed down by hand all of the block numbers-2 1/2 million of them--to make the 32,000 separate map sheets that covered the United States for the 1980 Decennial Census. This was all done initially during the 2 year period before the census with cleanup activities continuing using a greatly reduced staff for 2 years after the census.

At a slightly earlier period in time, over 300 local agencies scattered across the country were busy creating GBF/DIME-Files by transcribing the street names shown on earlier versions of many of these same maps, all of the block numbers within the areas covered by the files, and the address ranges that went with those street names and block numbers. All of this information subsequently was keyed and converted into a series of computer files.

At a slightly later period in time, another group of people (about 300 of them) took these same maps and transcribed the same block numbers, along with the ED numbers, census tract numbers, place names and codes, county names and codes, and so forth in which the blocks were located. This information also was keyed and converted into a series of computer files, state-by-state.

Said another way, three different times, with three different groups of people, we recorded the essential information about the earth in census terms. We then matched all three of these products together and were confronted with the fact that they didn't match perfectly. For example, in Figure 3, the place code in ED 23 was written as 8885 instead of 8855, which caused a mismatch between the Master Reference File and the maps and GBF/ DIME-Files.

Perhaps we should not have been surprised because people do make mistakes as they perform repetitive clerical tasks. Also, it is not reasonable to assume that mistakes will be made on the same area by different people--they each make mistakes in their own way. It is the process, not the people, which is the cause of the problems; this series of complex and functionally separate operations which were used to create the 1980 geographic products... and the 1970 geographic products... and the 1960 geographic products.

THE PLAN

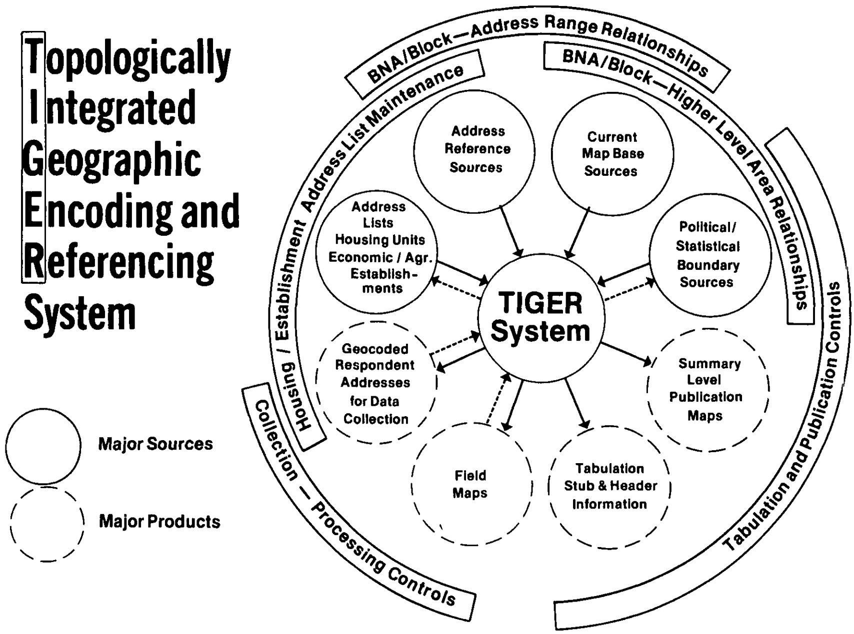
The expanding role of censuses and surveys in meeting the Nation's data requirements necessitates a substantial improvement in the delivery of these critical products and services. To this end, the Bureau has enunciated a series of long-term goals, one of which is:

> "To improve the efficiency of Census Bureau activities by inaugurating an automated system of geographic support services."

The improved geographic support program designed to meet this goal in time to benefit the 1990 Decennial Census involves the recording of all relevant available geographic information about an area in a single computer file. This file, once completed for an area, will permit the assignment of geographic classification codes to individual residential and business addresses, allow for the generation of maps for field operations and publications, and provide the geographic framework for tabulation of data to any unit whose boundaries have been recorded in the file. Further, because all products will be produced from one file, the possibility no longer exists for the maps to show one block number, the GBF/DIME-Files to show a second block number, and the geographic reference files to have a third block number. The same block number will appear in all three products.

Based on the assimilation of advice and suggestions from a broad spectrum of academic disciplines and acknowledged experts in several fields, a preliminary design for the structure of the desired computer file has been developed. The file structure adapts the mathematical theories of topology to cartographic presentation and geographic relationship storage and retrieval problems. For discussion purposes, this file is called the Topologically Integrated Geographic Encoding and Referencing File, or TIGER file. (See Figure 4.)

Figure 4



To convert the functionally separate, clerically intensive geographic support operations of the past into an automated system capable of delivering high quality, timely geographic products and services for 1990 is an enormous undertaking. It will require a "one-time" major allocation of resources to make a fundamental change in the way geographic support is provided to the Bureau; to provide for the transition from the methodologies of the past to the approaches made possible through automation. This fundamental change in approach will enable us to deliver not only the previously required types of geographic support services, it will provide the Bureau with the capability to automate many other aspects of the data collection/processing/publication continuum--especially, those which are geographically based.

The geographic support program described in this paper includes both activities which will be automated and those related activities which will continue to use traditional processes. For example, the collection and preparation of the geographic information which will be entered into the computer file (current base maps, address range listings, geographic area boundaries, and so forth) will be done in traditional ways; the entry of that information into the computer file, the editing of the computer file for completeness and consistency, and the production of maps and other geographic materials will make use of automated processes that will greatly increase the efficiency and quality of the services and products provided.

The computer file that will be at the heart of the automated geographic support program will integrate four major functional components:

1. The capability to document the nominal and hierarchical relationships of the geographic areas represented in each census or survey: the 50 states, the 3,137 counties or county equivalents, the 18,000 plus minor civil divisions or equivalent areas, the more than 20,000 incorporated places, and so forth. Each area's name and its identifying code(s) will be recorded. The area's geographic relationship to all other areas in the file (the Master Reference File of 1980) will be derivable automatically.

2. The capability to assign household or business establishment responses to the appropriate geographic location based on the structure address. This is the process referred to as "geocoding" that was done by the 1980 GBF/DIME-Files.

3. The capability to accurately portray the boundaries of all political and statistical areas recorded in the geographic component of the TIGER file plus the streets, roads, and other relevant map features needed for field operations as recorded in the geographic assignment component of the TIGER file. This component must provide a mechanism for update of the features and boundaries comprising the file to reflect changes. It will then be possible to produce the maps using automated methodologies.

4. The capability to provide a geographic control system that meets the operational requirements of the field data collection activities, the processing center activivities, and the data tabulation/dissemination functions. For example, the production of maps for use in followup assignments, the printing of lists showing blocks in relation to various higher-level geographic units, the preparation of management reports showing the status of various geographic operations, and so forth.

Each record in the file will contain information, such as:

° The name and type of the feature; for example, whether the feature is a road or street, a waterway, a railroad, a political boundary, and so forth.

° The coordinate values defining intersection points along the feature, along with other geometric characteristics of the feature; for example, the curve vectors defining the shape of the feature.

° The range of addresses located between intersection points for those records representing streets or roads, in addition to the post office name and ZIP code associated with that address range.

° The codes for the geographic area(s) applicable to each segment of the feature based on the geometric relationship of the boundaries in the file to the feature.

° Other special situations associated with the record; for example, major employment centers or residential structures located along the feature.

Once constructed, the TIGER file provides a geographic framework from which the maps required for field operations or publication products could be generated; a means through which the housing units or business establishments in a census or sample survey could be assigned to a specific geographic location; a basis upon which an automated questionnaire check-in and control system could be established, permitting generation of follow-up assignments based on structure address or serial number in geographic perspective; and, a source file from which geographic table stubs and summary cartographic products could be generated for tabulation purposes.

While this plan is very ambitious, it is "do-able" by 1990 if we organize our resources properly and take advantage of the work done by others. We look forward to discussing this plan with you in the days and months ahead.

STATISTICAL MAPPING CAPABILITIES AND POTENTIALS OF SAS

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ABSTRACT

SAS, the statistical analysis, data management and graphics system (with SAS/GRAPH) offers several procedures and programming capabilities that provide for the efficient analysis and mapping of geographically based statistical data. Cartographic data is stored in a standard statistical file providing efficiencies in storing and making the data easy to create, document, access, manipulate and transfer between users. Mapping procedures are available to perform map projections, boundary line generalization, the redefinition of geographic regions from existing files and the output of several types of statistical maps to a variety of widely available graphics output devices, including color. Many useful features support computer-assisted statistical mapping and graphing for data display and analysis. The easy exchange of cartographic and statistical data files between researchers at widely separated locations is facilitated, while insuring file compatability. The present and future cartographic potentials of SAS are explored, along with examples of statistical map output.

INTRODUCTION

In the early 1970's, statistical computing began to change, with the introduction of integrated statistical packages. Tney permitted a user to perform one or more statistical procedures on a single data set stored in a standardized file format. The widespread adoption of such packages by researchers and teachers in social sciences led to the widespread acceptance of statistical computing. Packages such as SPSS, DATATEXT, OSIRIS, SAS and others were used in graduate and undergraduate training. Geographers and others who work with spatial (geocoded) data also employed these packages, but found that maps still had to be produced by manual methods, a slow and tedious chore. On the other hand, computer mapping packages developed and distributed by Harvard University's Laboratory for Computer Graphics and Spatial Analysis reduced the labor intensive map making task, however they lacked the capability to easily transform or manipulate the attribute or cartographic data. In addition, data handling was cumbersome because the mapping packages lacked standard system data files and the data management capabilities which are part of most popular statistical packages.

While many technological advances have lowered costs in computer graphics technology, a growing need for statistical and other thematic maps and graphs combined with software advances have placed statistical cartography in the position of statistical computing five to ten years ago. SAS/GRAPH, a statistical graphics and computer mapping system integrated with SAS, now provides map makers with a tool for the easy use of geographically based data that overcomes the limitations outlined above. The purpose of this paper is to examine some existing mapping capabilities of SAS/GRAPH and potential applications that will benefit the statistical mapping community.

SAS MAPPING FEATURES

SAS is an integrated statistical analysis, reporting and data management software package. In 1980, SAS added SAS/GRAPH, a package for statistical graphing and mapping that could be implemented at existing SAS installations. The combination of features in both packages provides a very powerful tool for those who analyze spatial data and require statistical graphs and maps as output. SAS/GRAPH has four procedures for computer mapping applications (SAS Institute, 1981, 1982a). They are:

1. PROC GREDUCE filters out points contained in the map data set that are not needed for the proper appearance of the map (Douglas and Peucker, 1973). The results are reduced storage requirements and processing costs.
2. PROC GREMOVE deletes internal boundaries of regions to redefine the geographical hierarchy. For example, Census regions are created by removing selected state boundaries from the United States map data set and keeping only those boundaries which make up the external regional boundaries.
3. PROC GPROJECT applies either the Albers equal area, Lambert conformal conic or the gnomonic projection to a map data set containing the unprojected coordinates stored as radians.
4. PROC GMAP produces the map output by using both the map and attribute data sets. Types of plotted output presently includes the choropleth, prism, block and surface maps.

The SAS programming statements used to produce a map or perform utility operations on map data sets are few in number and simple to learn. The ability to analyze, manipulate and manage data requires some understanding of how SAS processes data. This necessitates some training and practice, much the same as if one were using the statistical procedures. Since SAS is a data processing package, one of the major problems it solves for computer mapping is the management of the many, sometimes large data sets required for computer mapping projects.

HARDWARE UTILIZATION REQUIREMENTS

While SAS is presently running on IBM 370 compatible mainframes under several different operating systems, a version for Data General "super" minicomputers (32 bit), has been announced by the SAS Institute (SAS Communications, 1982b, p. 3). The somewhat limited choice of mainframe computers, however doesn't apply to the choice of graphic output devices. At the present time, many different models of interactive monochrome and color CRTs and hard copy plotting devices from more than a dozen manufacturers are directly supported by SAS/GRAPH. In addition, a "universal device driver" will interface those graphic devices not directly supported. Program directed options available to the programmer within SAS/GRAPH resolve hardware differences and also take advantage of special features that are built into certain graphics terminals and plotters. For example, if a user works with a Tektronix 4027 color crt, SAS/GRAPH has a procedure that will enable the terminal's function keys to help streamline a terminal session. Thus, different hardware characteristics are resolved by the software for each specific device. Printer produced maps resembling SYMAP are not available in SAS, but some attempts to program them have been made by individual users (Spitznagel, 1980).

SAS MAP DATA SETS

One of the most powerful features of SAS is the ability to read and store nearly any type of machine-readable data using any of a variety of input formats. A single SAS data set can store over 1000 variables and an unlimited number of observations. Map data sets require several variables, including a geographic code variable, horizontal and vertical coordinates, and segment identifiers to accomodate any case in which a single region is made up of more than one polygon. Hierarchical files are also accomodated by SAS.

When creating a SAS map data set, variable names are stored with the data set as are user comments. The later are a valuable documentation feature, especially for storing a description of the data. For example, map data sets might contain statements describing the coordinate system, the source, scale and projection of the source map, the name of the digitizing orgainization and any other information required for internal documentation. Any subsequent user of the map data set can print the internal documentation by using PROC CONTENTS. In addition, automatic documentation such as the type of storage device, names and sizes of files, the time and date of creation, the names and data formats of all variables are also printed. Another useful feature is the ability to store geographical area names up to 200 characters long as a single variable.

The importance of complete map file documentation has been a subject addressed in the cartographic literature. Information stored internally with the data will not be missing or hard to find as is sometimes the case with separate printed documentation. Universities, governments and private industry concerned with maintaining data archives are concerned with data integrity that includes adequate documentation for cataloging machine-readable data files. SAS facilitates the efficient management of large data bases through internal data set documentation. Since map data sets are expensive to create and maintain, efforts should be made to protect this investement with proper documentation.

Good documentation also facilitates the transfer of data between widely separated installations. Problems associated with tape file transfers are minimized with SAS data sets, often saving much time and effort when tape based files are transferred from one place to another.

USING THE MAPPING PROCEDURES

The SAS Institute supplies four map data sets (cartograpghic data bases) with SAS/GRAPH. They are:

1. United States by state (unprojected)
2. United States by county (unprojected)
3. United States by State (projected and reduced)

4. Canada by province and census district (projected and reduced).

Only the reduced and projected United States map data set is in a form ready to be used in a mapping procedure. The other data sets must be projected and/or reduced before they can be used.

Preparing SAS map data sets for a mapping project is easy and may be accomplished within the same job that produces the map. In normal practice, map data sets are prepared once and stored for later use with the mapping procedure for the sake of economy. If, for example, a map were needed that required the data contained in the unprojected "states" map data set, several preprocessing steps would be necessary. Our example will assume we want to create a map of the four census regions for the contiguous United States.

The first step would consist of removing the state boundaries internal to the census regions using PROC GREMOVE. To accomplish this, we create a data set with cross references from each of the 48 states to its corresponding census region. This data set is then merged with the map data set so that each of the 15,506 observations contains the appropriate region code. This is easily accomplished with several SAS statements that invoke the data management programming steps of SAS. Next, the data is processed by PROC GREMOVE, resulting in the creation of a data set containing the desired regional boundaries. A map of the census regions is shown in Figure 1. If it were necessary to reduce

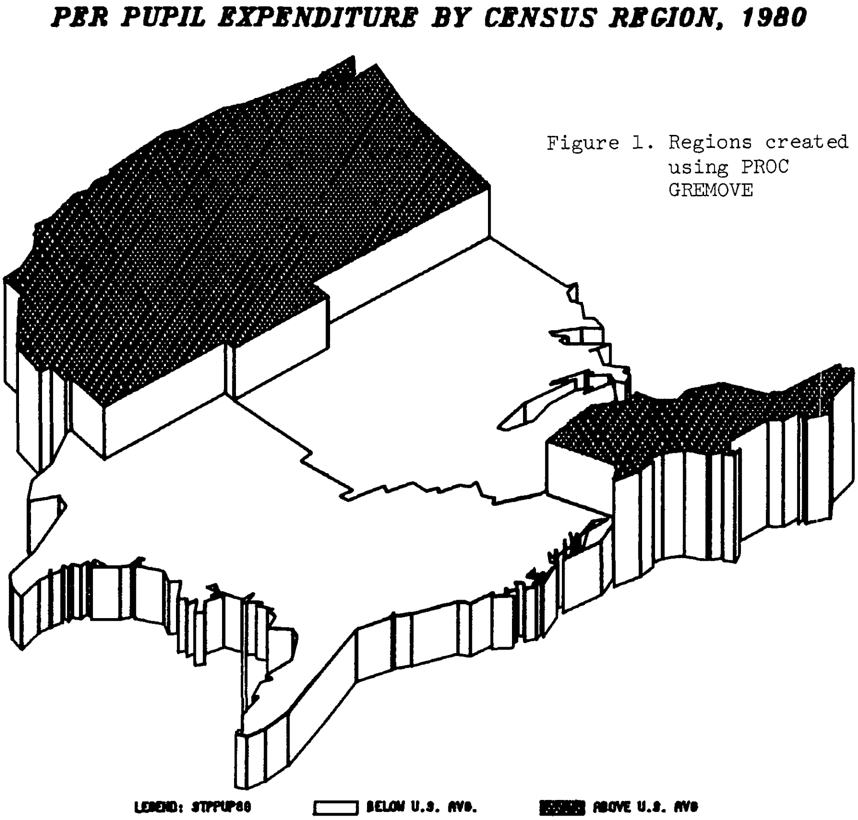

Figure 1. Regions created using PROC GREMOVE

the physical size of the final output file or limit the maximum number of coordinates per polygon, then PROC GREDUCE would have been used prior to creating the final map data set. PROC GREDUCE employs a line filtering algorithm to reduce the number of coordinates in a digitized line. For this particular figure, however, the projected and reduced United States map data set was used.

Next, the data set containing the census regions is processed by PROC GPROJECT, the final step necessary prior to mapping when an unprojected map data set is selected. For the United States, the default Albers equal area map projection is appropriate. If one of the three available map projections is not suitable, then SAS programming statements could be employed to compute the desired projection for the particular data set. The ease of using programming statements within SAS by a user makes it a very flexible package for performing any type of transformation on map (or attribute) data and mapping the result.

Statistical maps are produced by selecting an attribute data variable and matching it with the appropriate geographical code stored in a map data set. The link between map data and attribute data is the geographic code contained in each data set. The mapped variable is specified by name, the geocode variable name is identified, the map type specified and the number of symbolism classes (if appropriate) is chosen. Since the attribute data controls which polygons are plotted on the map, subsets of large data sets need not be specially created. For example, if an attribute data set contained only data for the states of the southeastern United States, then only they would be plotted from a map data set containing all forty-eight states.

The plotter output space has title space at the top, footnote space at the bottom and map/graph space between the two. SAS/GRAPH scales a map to fit in the plotter space remaining after titles and footnotes are plotted. If a series of maps are being produced, for example, then a constant number of title and footnote lines on each map will result in each one being at the same scale. If necessary, dummy title and/or footnote lines should be inserted for consistancy.

The choropleth map is frequently selected to display statistical data and it is available in PROC GMAP. Here an example of a choropleth map of the southeastern states is shown (Figure 2). The newest types of maps available in SAS/GRAPH are the prism and block maps which were released in the latest version of the package (SAS Institute, 1982a). The prism map example shows the 1980 populations for twelve south-eastern states (Figure 3).

The final example is the block map, consisting of graduated vertical bars placed at the centroid of each polygon. The map of Greensboro's 1960-1970 population change is a block map (Figure 4). The map data set containing the census tracts is a modified version of the Urban Atlas map files developed by the U.S. Census Bureau (Schweitzer, 1973) and distributed separately by the SAS Institute as a map data set. The 1970 tract boundaries are available for over 200 cities of the United States. The Urban Atlas data set is much easier to use for mapping as a SAS data set than the original version. Although the 1980 tract boundaries are not available, the 1970 tract boundaries, still have value as an educational tool.

SAS facilitates statistical mapping. Features such as the standard file format for the storage of both attribute and map data, internal documentation, data transformation, manipulation and management give the map maker many capabilities combined with the flexibility of SAS. Map making requires a few simple SAS statements to create any of several types of statistical maps. The possibility of creating, storing and archiving map data sets will permit SAS users to carry out large projects that necessitate the use of large attribute and/or map data sets. SAS is well supported with frequent updating, the addition of new procedures and a large, active world-wide user group that convenes annual meetings and publishes proceedings.

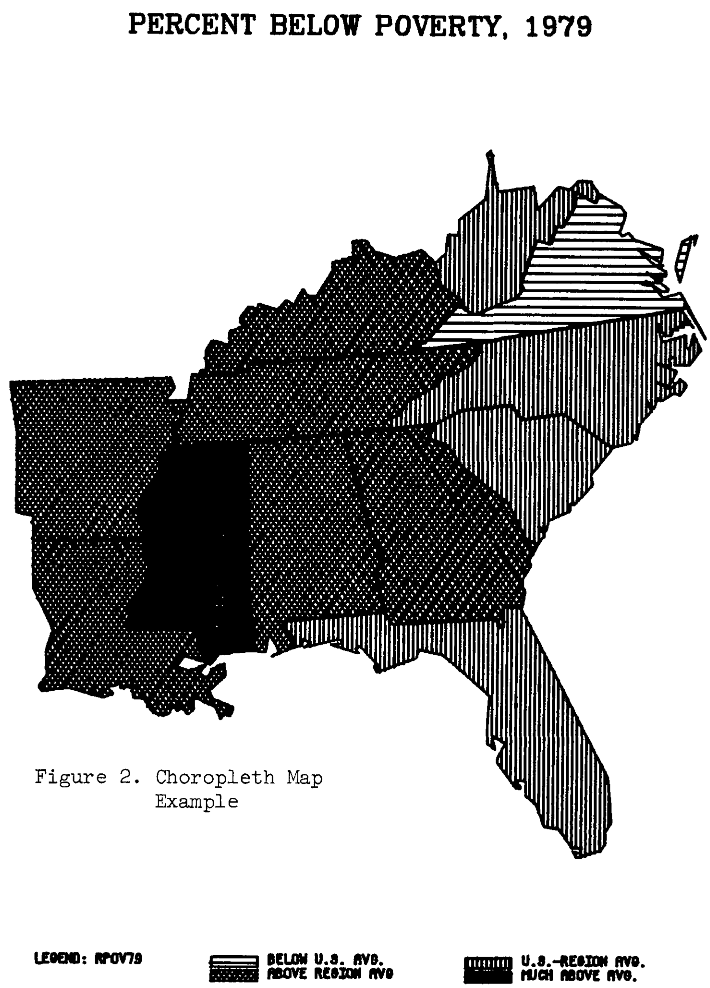

Figure 2. Choropleth Map Example

SOUTHEASTERN U.S. POPULATION, 1980

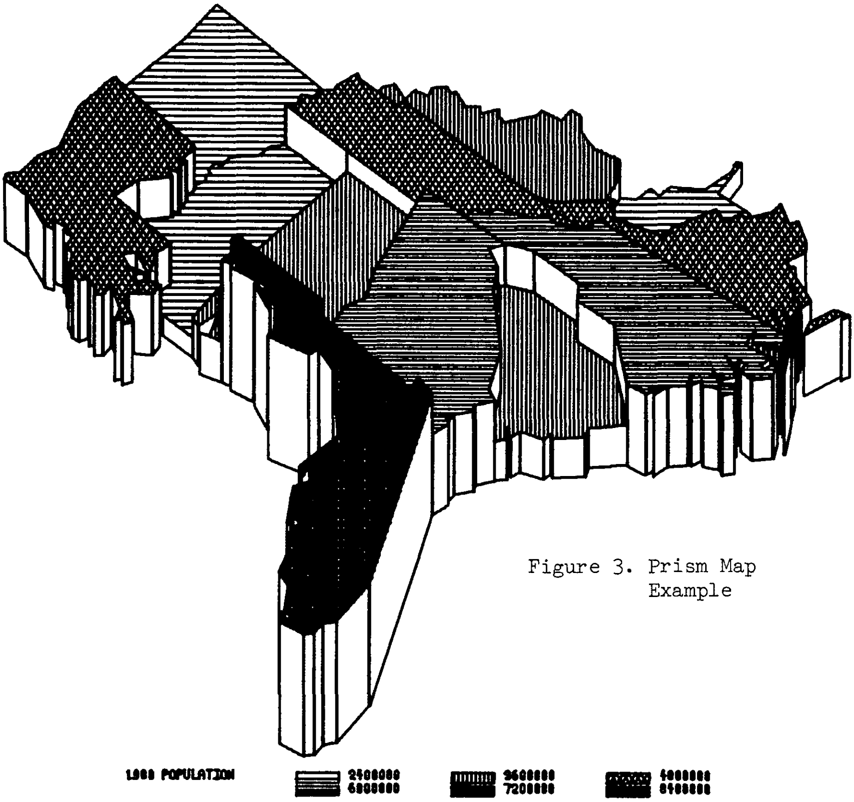

Figure 3. Prism Map Example

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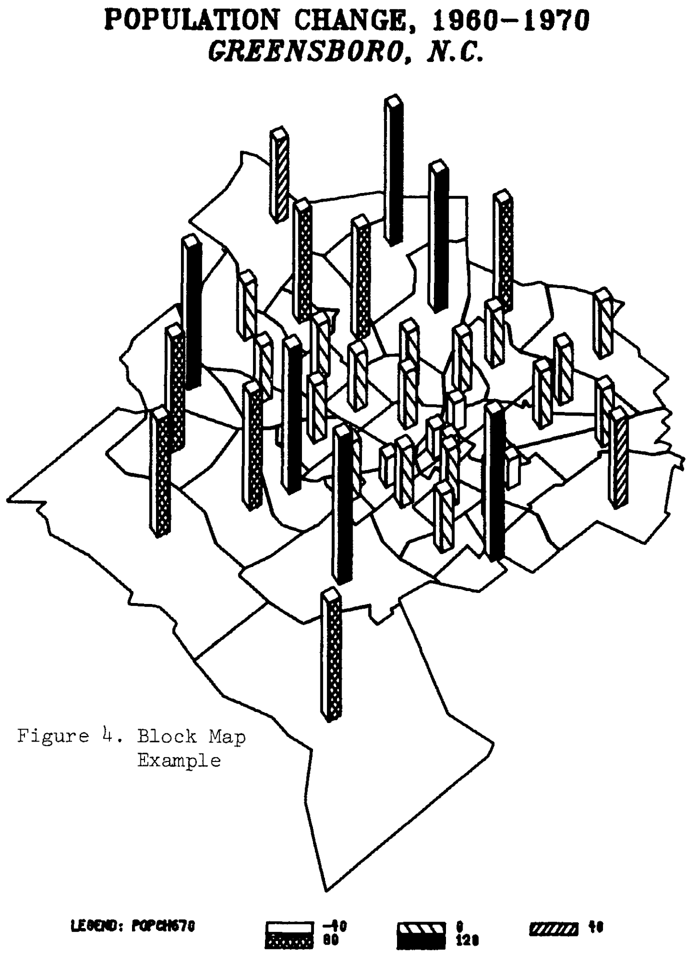

Figure 4. Block Map Example

A RASTER-ENCODED POLYGON DATA STRUCTURE FOR LAND RESOURCE ANALYSIS APPLICATIONS

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ABSTRACT

A prototype structure for areal data sets is discussed in the context of providing efficient data storage, retrieval, and analysis as required by land resource analysis applications. The prototype is a "raster-encoded polygon format" and is derived from a run-length raster format in which each run has multiple attributes associated with it. A transformation program, involving the first phase of the raster-to-vector conversion process, associates each run with a parent polygon entity. The total size of each entity, and information concerning its adjacency to other entities, are recorded in an entity table along with all attribute values for the entity. This results in a reduction of total volume of the run-length raster file, and simplified subsequent manipulation and retrieval operations based upon attribute values of the data. The underlying raster structure retains its advantages for overlaying new data sets and complex retrieval operations. Since the parent polygon area and adjacency relationships are identified, queries based upon threshold size or adjacency can now be addressed with what is essentially a raster data structure.

INTRODUCTION

Land resource analysis involves the evaluation of the capabilities and constraints of the physical characteristics of a region, usually conducted in support of some decision-making process of public or private agencies. The evaluation produces quantitative information and supporting graphics from maps and supplemental information contained in inventories of land resource characteristics. Geographic information systems have been developed to enhance the evaluation of land resources, as well as for conducting other forms of spatial analysis. The distinguishing characteristic for land resource analysis applications, however, is that diverse data sets (particularly areal data sets) must be integrated in order to develop satisfactory solutions to the questions being addressed (Knapp, 1980). This, in turn, has significant ramifications for the manner in which spatial data is organized for use in a geographic information system.

Discussion of spatial data organization have centered on differences between raster and vector data structures. For purposes of inventory, and less complex retrieval and analysis operations, vector formats are preferred for areal data (Tomlinson and Boyle, 1981). When data from several sources must be merged, however, as is frequently the case for land resource analysis, vector formats are not advantageous because of difficulties which most systems have in performing polygon overlay (Tomlinson and Boyle, 1981). These difficulties affect the ability to merge data initially, to retrieve data from irregular areas of interest in a region, and to modify and update data sets. Raster formats have been recognized as advantageous for overlay and many retrieval and analysis functions. The problem of data storage, retrieval, and analysis for large data sets resulting from a high resolution raster scan

can be ameliorated by using compression techniques. A variant of run-length compression has been described previously and used successfully to merge and retrieve areal spatial data (Miller, 1980; 1981). This technique uses a group of adjacent columns of grid cell data along a row (i.e., a run) as a spatial unit (see Figure 1).

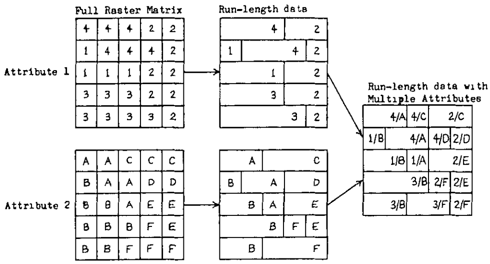
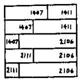


Figure 1. Derivation of run-length data with multiple attributes.

In spite of the advantages offered by compact raster processing, it is unable to fulfill the requirements for certain types of query. Queries based upon size and adjacency of composite polygon areas, for example, cannot be addressed since the basic spatial unit corresponds only to a horizontal portion of a polygon. Vector formats or, as Knapp observes, "entity based data structures," can much more readily respond to such queries (Knapp, 1979). The realization that alternate formats offer advantages for different operations has led to increased interest in the problem of raster-to-vector and vector-to-raster operations (Nichols, 1981). The ability to interchange formats is certainly appealing and it offers a solution to problems of storage, retrieval, and analysis for land resource applications. Yet the cost of such transformations, particularly the raster-to-vector transformation, can be large. Once accomplished, it is likely that the data will subsequently need to be transformed back into raster format for any complex retrieval and analysis operation. In light of this, a case can be made for developing a hybrid raster format which takes on certain characteristics of polygonal data structures. A prototype for such a data structure, suitable for land resource analysis operations, is presented in this paper.

RASTER-ENCODED POLYGONS

An early line-printer mapping routine, developed originally by the Bureau of the Census, was entitled CMAP and it is an example of the raster-encoded polygon (REP) data structure (Monmonier, 1973). For CMAP, thematic mapping units, such as states, counties or census tracts, were encoded in a run format. The administrative codes for the mapping unit were associated with each run segment and a table of values (see Figure 2). From the raw values in the table (e.g., percentage of owner-occupied houses), a class interval number and associated overprint characters could be assigned. More recently, designers of the Domestic Information Display System (DIDS) coined the term "raster-encoded polygon" and employed a data structure somewhat akin to that of CMAP. Instead of a line-printer, DIDS uses color graphics display terminals that have been developed for the field of image processing (Dalton, et al, 1980). Refinements added to the data structure allow the data to be zoomed in selective increments without loss of significant boundaries.



Census Unit	Value	Class	Symbols
1407	92%	5	O V A X
1411	78%	4	O V X
2106	42%	2	O /
2111	58%	3	O X

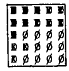
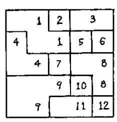


Figure 2. Line printer mapping of raster-encoded polygon data.

As with most applications involving run-length data sets to date, DIDS dealt with a single coverage, namely, administrative boundaries (i.e., state, county, and selected municipal and census tract boundaries). Data compression ratios of 10:1 and better were observed under these conditions. For natural resource applications, however, multiple coverages are needed. Yet what has generally not been appreciated is the fact that data compression ratios in the range of 4:1 to 6:1 and better have been observed for multi-layered data sets involving up to nine coverages (Miller, 1980). What is suggested, then, is that a multi-layered compressed data set as depicted in Figure 1 can be transformed into a raster-encoded polygon data set (see Figure 3). The polygon entities derived from this transformation correspond to mapping units as defined for CMAP and DIDS. Instead of a single attribute and code, however, codes for multiple attributes are associated with each entity in a table.



ENTITY TABLE

Entity	Attributes		Area	MinLine	MaxLine	MinElem	MaxElem	Pointer-Adjacency Table
1	4	A	4	1	2	1	2	5
2	4	C	1	1	1	3	3	8
3	2	C	2	1	1	4	5	12
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
12	2	F	1	5	5	5	5	(last element)

ADJACENCY TABLE

Entity	Length	
null	3	
2	2	
5	1	
4	3	
7	1	Last edge for entity 1
null	1	
1	2	
3	1	Last edge for entity 2
null	3	
2	1	
5	1	
6	1	Last edge for entity 3
⋮	⋮	
null	2	
8	1	
11	1	Last edge for entity 12

Figure 3. Entity and adjacency tables of a raster-encoded polygon data.

TRANSFORMATION OF COMPRESSED RUN-FORMAT DATA INTO RASTER-ENCODED POLYGONS

The transformation of compressed run-length records involves at least two distinct steps assuming the data currently exist as single overlay files. The data must be merged and an efficient method of performing this task on sequential lists of run-length records has been previously described (Miller, 1981). The algorithm compares successive ending-column locations looking for the minimum for runs along a row or scan line on two or more coverages. Pointers to the attribute list provide the attribute information, while the minimum ending-column determines the ending column location of the composite run. Secondly, any redundancy which exists in the composite data should be eliminated. The routine for deriving composite records which is described above will ensure that no redundancy exists in the initial composite data set. If, however, only a few attributes are chosen for subsequent processing, further compression of the data may be possible. Any redundancy should be removed in order to simplify the transformation of the data to the raster-encoded polygon structure.

The transformation of compressed raster data into a raster-encoded polygon structure builds upon the work of other researchers. Rosenfield describes an algorithm for segmentation--the assignment of individual raster elements to a significant entity (Rosenfield, 1979). Nichols adapted the algorithm suggested by Rosenfield and developed an effective raster-to-vector conversion method (Nichols, 1981). The first phase of the raster-to-vector conversion involves labelling and edge processing. For a complete raster-to-vector algorithm, subsequent phases are needed to link edges into chains; to weed and smooth redundant coordinates in the chains; and, finally, to piece together the chains needed to define polygons. The labelling and edge processing phase, however, is considerable less involved than subsequent phases and a strong argument can be made for delaying any further processing since this phase provides the data needed for land resource applications.

An algorithm has been developed to perform the labelling and edge-detection phase for multi-layered data in a run format. The first step in the algorithm suggested by Rosenfield requires that redundant elements along a row be eliminated. Since the redundant data has already been eliminated for the run format data, a slight amount of processing time is saved. A description of the transformation routine follows.

```
procedure    Build Entities
begin
             LoadScan (lscan, latt, nrls, eof)
             for i:=i,nrls do begin
                  lscan(i,3)=i
                  EdgesAcross (lscan,i,null, null);
                  Uptable;
             end;
             nent=nrls
             EdgesDown (lscan, nrls)
NextScan     LoadScan (cscan, catt, nrcs, eof)
             if (eof) then begin
                  for i:=i, nrls do
                       EdgesAcross (lscan,i,null,null);
                  end;
                  stop
```

```
          j=1
          for i=i,nrcs do
Att-Check      for K:=i,natt
                    if (catt(i,K)≠latt(j,k)) then
                         EdgesAcross (lscan,j,cscan,i)
                         go to J-Update
               end;
               if (cscan(i,3)=0) then
                    cscan(i,3)-lscan(j,3)
                    go to J-Update
               Write UF (lscan,j,cscan,i)
J-Update       if (cscan(i,2)=lscan(j,2)) then
                    j=j+1
                    go to Nent-Check
               if (cscan(i,2)<lscan(i,2)) then go to Nent-Check
                    j=j+1
                    go to Att-Check
Nent-Check     if (cscan(i,3)=0) then
                    nent=nent+1
                    cscan(i,3)=nent
                    Uptable
          end;
          EdgesDown (cscan,nrcs)
          Shiftscan (lscan, nrls,cscan, nrcs)
          go to Next-Scan
end;
```

For the previous or last scan line, *lscan(j,1-3)* respectively contain the beginning and end column position and the assigned entity code (i.e., a sequence number). The *jth* entry in *lscan* corresponds to the *jth* entry in *latt,* which holds code values for the *natt* attributes in the file. The *cscan* and *catt* arrays are similar to *lscan* and *latt,* except that they refer to the current scan line. Two values, *nrls* and *nrcs,* refer respectively to the number of records for the last and current scan.

The algorithm loads the first scan line of data into the *lscan* and *latt* arrays. Boundary lengths between the outer area (null) and the runs along the first scan line are then computed by the *EdgesAcross* function and written to the edges file. Function *UpTable* builds the initial version of the entity table. The current number of entities *(nent)* is set to the number of records in the initial scan line *(nrls)*. Of course, the vertical, pixel-length boundaries between runs along a scan line must also be computed and the function *EdgesDown* performs this task.

Function *LoadScan* loads the series of run records for the next scan line. At the end-of-file, *EdgesAcross* must again be used to compute lengths between runs along the last scan line and the outer boundary. For all scan lines between the first and last, consecutive lines are examined in order to determine which entity number should be assigned to each run along the current scan line. For a run along the current scan line to be considered contiguous to a run from the last scan line, at least one pixel overlap must exist. For the contiguous runs, all attribute code values must match before *cscan (i,3)* can be assigned an entity sequence number. If any of the *natt* attributes does not match, the vertices, and length of the edges between the two runs must be computed and written to the edges file. Function *EdgesAcross* handles this task.

If *cscan (i,3)* is presently unassigned, it takes on the value of *lscan (j,3)*. If not, then the current run overlaps and matches more than one run from the previous line and function *Write UF* must write an edit request to an update file so that previously processed records can be assigned properly in a second pass. This is necessary since polygons coalesce as the processing proceeds from one scan line to the next. Assigned entity numbers, both in the entity table and in the edges file, must be updated. Since the entity table would be stored in memory, pointers can be updated. For the output raster file, and the edges file, however, a second pass is required to update previously assigned entity numbers (see Figure 4).

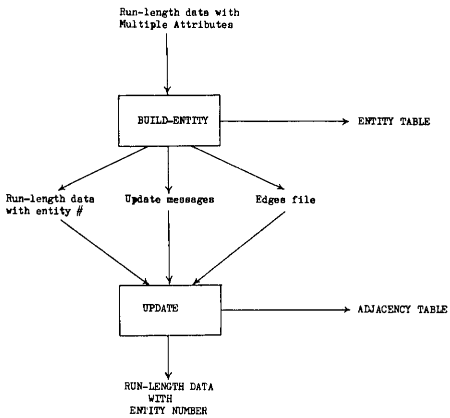


Figure 4. Flowchart of the Build-Entity Procedure

ADVANTAGES OF THE RASTER-ENCODED POLYGON DATA STRUCTURE

The raster-encoded polygon (REP) structure offers certain advantages for storage, manipulation, and retrieval over conventional forms of both raster or vector format data. With regard to storage, a run notation is maintained with the REP format. Instead of each run record carrying all associated attribute code values, however, only a single value, the index to the entity table, is associated with each run record. This reduces the volume of the raster data file over that of either conventional or compressed raster notations. Manipulative operations, especially those involving attribute-checking such as merge and dissolve, are perhaps most effectively carried out on topologically-structured vector data. Yet such operations can be done quite efficiently on the REP format since the entity table provides complete attribute and adjacency information. A pass through the entity table provides the index numbers which meet constraints for adjacent attributes and a pass through the data file provides all run segments associated with the index numbers.

Perhaps the chief advantage of this format, however, lies in the fact that subsequent merging and retrieval operations can be carried out efficiently on the REP format, since the basic raster organization of the data is maintained. Windowing operations are clearly more easily carried out in raster format for both regular and irregular windows.

For example, the difficulties associated with polygon overlay make it problematic to define and retrieve vector data from irregular window areas such as corridor search zones around convoluted stream segments. As long as these problems remain and these types of query remain important to land resource analysis, raster formats such as those implicit in REP will continue to be advantageous and preferred for storage of areal data in a spatial data base management system.

SUMMARY

The design and development of effective spatial data base systems for land resource applications requires an understanding of the importance of the polygon overlay capability. Of course, the problem can be dealt with in one of several ways. First, it is possible for well-defined research management problems to limit the number of overlays involved. The concept of "integrated terrain unit mapping" advanced by Dangermond (1979) avoids the problem of polygon overlay, at least for the initial task of creating the data base. Also, there are methods of polygon overlay which work, though few, if any, seem to work on sizeable data sets.

None of these solutions seem acceptable for most land resource analysis applications in which data requirements are diverse, data sets may be added incrementally, and the data base needs to cover large geographic areas at scales and resolution which result in complex vector data set. Resorting to a vector-to-raster conversion to facilitate overlay, and then from raster-to-vector for storage, seems a bit short-sighted. Study areas seldom coincide with sheet boundaries and the outlines of prospective study areas will usually not have been anticipated. This means that it must be possible to retrieve data routinely for highly irregular search areas. Only raster data formats and particularly compressed raster data sets, can address these types of query efficiently. On the other hand, vector formats for polygon data are truly advantageous for searches involving threshold sizes and adjacency. By transforming the compressed raster data into an entity-based data structure such as REP, it will be possible to efficiently address these types of query.

These advantages, coupled with advances in raster-based computer hardware, seem to indicate that the REP data structure holds much promise for land resource applications. Others have demonstrated, for example, that the hardware required to generate video signals from run-length encoded records is straightforward (Newman and Sproull, 1979). Color or grey-tone values for a look-up table could be generated easily from the entity table. These advances in data structure, coupled with less expensive micro-based hardware systems, hold much promise for geographic information systems developments in the 1980s.

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DEFENSE MAPPING AGENCY LARGE SCALE DATA BASE INTEGRATION

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ABSTRACT

The Defense Mapping Agency (DMA) has massive amounts of MC&G digital data holdings resulting from programs to support DoD advanced weapons systems and automated map and chart production. The digital data is used to support the DoD and other countries as well as internal DMA production. DMA requires a digital data base to maintain, store, retrieve, compare, and report on this MC&G digital data. This paper addresses current DMA efforts that will evolve into an on-line interactive, distributed, networked data base system and its associated environment for data handled by HQ DMA and the DMA Production Centers.

BACKGROUND

The Defense Mapping Agency (DMA) has massive amounts of MC&G digital data resulting from programs to support DoD advanced weapons systems and automated map and chart production. The digital data is used to support the DoD and other countries as well as internal DMA production. DMA requires a logically single automated digital data base to maintain, store, retrieve, compare, and report on this MC&G digital data.

The collection of digital data began in the 1960's when the DMA Hydrographic/Topographic Center (HTC) (formerly the U.S. Army Map Service) began collecting terrain data for use in an automated system of carving three-dimensional relief maps. A digitizing table called a Digital Graphics Recorder (DGR) recorded the position and elevation values of traced contour lines from cartographic source materials. The final output magnetic tape controlled a carving or milling machine.

In 1966, the Universal Automatic Map Compilation Equipment System (UNAMACE) was put into production at HTC. Digitized elevations are produced directly from rectified stereo imagery and are used to output orthophotographs, altitude charts, and terrain elevation matrices.

In 1972, the DMA Aerospace Center (AC) entered a new realm of production with a digital product to simulate radar displays for pilot training which today is referred to as the Digital Landmass System (DLMS). The DLMS product requires a matrix of terrain elevations called Digital Terrain Elevation Data (DTED) which, at the level of least refinement, is produced by 1-degree squares with elevation values (posts) at 3-second-of-arc intervals in both directions. DLMS also requires cultural data called Digital Feature Analysis Data (DFAD) to predict the radar reflectivity of the earth's surface. The DLMS production program covers over 18 million square nautical miles. It requires the collection of data from cartographic and photographic source materials using the Automatic Graphic Digitizing System (AGDS) (AC and HTC), stereoplotters (AC and HTC), DGR (HTC), and other systems from both Centers to meet the production goal. This program continues today.

In 1973, DMA recognized the need for a single data base system to provide centralized management for digital data related to advanced weapons systems and automated chart production processes. The Cartographic Data Base (CDB), which became operational in 1974, provided the centralized management needed to serve DMA. The CDB initially contained the DTED and DFAD produced from photographic and cartographic source materials at AC and HTC. The CDB provided digital data accountability, graphics of area coverage, and paper copies of historical portfolios for all digital production projects. The CDB was designed to have separate file management systems for each type of digital data in a modular design to generate, maintain, sort, and retrieve data, providing an integrated digital data base to meet production requirements. HQ DMA assigned the data base management function for digital data to AC in 1975.

As computer technology grew, production methods for required products created more MC&G data in computer readable form. The Semi-Automated Cartographic System (SACARTS) went into initial production at HTC in 1973. This system of computer hardware and software allowed the cartographer to digitize map and chart manuscripts codifying features such as lakes and roads. Taking hypsographic data from the UNAMACE and elevation and cultural data from vector or line digitizers (i.e., the CALMA and BENDIX), color separation scribe coat plates were produced on a precision Concord Plotter. AC also developed chart data in digital form called Automated Chart Features (ACF) data. Conceptually, the cartographer traces, tags, and edits features on the Automated Graphic Digitizing System (AGDS), composed of a digitizing table and two CRT's for menu selection and display. The resultant output (ACF data) drives a photohead plotter for the color separation plate.

New forms of digital products evolved out of expanded user requirements. In the 1970's, the Strategic Air Command (SAC) required Terrain Contour Matching (TERCOM) data to support the cruise missile. Also identified was the need for Vertical Obstruction Data (VOD) to support SAC. AC had maintained the DMA Vertical Obstruction File (D-VOF) to support manned or other flight vehicles.

The possibility of extracting data from one set to serve another purpose became more reasonable as more digital data became available. As an example of multi-use, DMA maintains a set of data known as Minibloc. Minibloc data is used for a special chart overprint where Maximum Terrain Elevation (MTE) readings for 10-minute x 10-minute areas are extracted from DTED. This was achievable with increased availability of DTED.

Because the simulations for flight training are becoming more realistic, it is anticipated that a user requirement for a visual data base simulation, which includes color of buildings, windows and other previously unrecorded details, will evolve into a validated production program.

Of major significance to DMA are such military applications of digital data as support of the major weapons systems. For example, the cruise missile guidance system uses TERCOM data; land combat simulation and analysis use digital terrain analysis data; and navigation and training simulators use Digital Landmass System (DLMS) data (DTED and DFAD).

As you can see, as a result of 15 years of generating digital cartographic data for various advanced weapon systems programs, DMA has accumulated 10^{11}-10^{12} (10^{12}-10^{13}) bytes of it. It's about time we figured out how to handle it.

DMA DATA BASE CAPABILITY EXPANSION

To manage and exploit the above-mentioned reserves of digital data effectively, DMA is currently involved in expanding its scientific and technical (S&T) computers with more memory and input/output devices as well as procuring a Data Base System (DBS) that will provide for an on-line, interactive, networked data base environment.

The tasks involved in achieving an interactive, networked data base environment with DMA are highly technical and complex. The current S&T computers will be upgraded to satisfy the needs for greater production thoughput. Concurrent with this upgrade will be the identification and implementation of the systems network. The DBS will be developed by a systems integrator (SI) that will be selected after a paid competition among two or more SI's. Each SI will provide a conceptual design of the DBS. DMA will select the best design for implementation. Each SI will be provided with a common set of DBS requirements in order for each to produce an appropriate design concept.

I will not dwell further on the hardware upgrade, software redesign, networking, or telecommunications tasks associated with the design and phased implementation of an interactive, networked data base system, but I will attempt to discuss DMA concepts of data basing in an interactive environment and data base design as it fits into the DMA MC&G arena.

A DATA BASE CONCEPT

The concept of an integrated data base needs to be substituted by that of a Leagued Data Base. Whatever we call the data base is not important. What is important is the concept behind the data base. For the sake of definition, however, the Leagued Data Base (LDB) is one with highly controlled logical redundancy in the schema which provides for improved usability of the data bases and enhances its life cycle performance.

The components of a LDB allow for collocation at a single site and distribution in a network. Most importantly, they are logically viewed as loosely coupled. Data base schemata must accurately and naturally model the application environment. It is important to recognize that a data base design that is equally good for all uses is also not particularly good for any of them.

In this regard, there is virtue in controlled redundancy. Alternate representations need to be maintained for a data item so that it may be accessed in different ways. One or several users may associate multiple meanings with a single item of information and use it in different ways. Therefore, this information should appear in several places in the schema that correspond to the several ways in which it is viewed. As an example, radio towers may appear in several different data bases. In one, the information may be needed by a field commander to ascertain communication links. In another, it may be needed by navigation planners for obstruction avoidance. Although this produces redundancy into the schema, it provides the user with the information where he wants it. Whether or not the data is physically replicated is an issue of efficiency, turning on whether the costs of maintaining two versions of the same data item is counterbalanced by the access efficiency two copies provide.

Cost is undeniably an issue. The cost of a data base in terms of space and time are not the only ones that define its performance, and it may no longer even be its most important component. The cost of building and maintaining the applications programs that make use of the data base may be even more important in selecting designs for the data base.

The performance evaluation of the Data Base System (DBS) and the Data Base Management System (DBMS) must be in terms of excess/inefficient processing, excess device capacity, lengthy application development times, frequent data base reorganization, required reprogramming of applications programs, and the complexity of applications programs due to the DBS/DBMS design. These evaluation terms are very difficult to quantify, if it is possible at all to do so.

DATA BASE DESIGN

Logical design begins with an investigation of user requirements and ends with a logical description (schema) of a data base that can support those requirements. The logical design is logical because it does not contain details about how the data is to be represented. This information is used during the subsequent physical design phase. Four activities are involved in the logical design:

- Requirements Analysis
- Data Modeling
- View Integration
- Schema Development

Data base physical design begins with a logical schema representing user requirements and processing requirements. Four activities are involved in physical design:

- Data representation determined and documented
- Access modes selected and documented
- Allocate data to devices
- Load and reorganize data bases

Certain specific tasks are then followed: Using the data definition language (DDL) of the Data Base Management System (DBMS), assign data type and size to each data element and group in the schema. Next, the access methods for storage and retrieval are chosen for each element, record, or file. These are recorded in the DBMS internal schema via the Device Media Control Language (DMCL). Now the actual data is loaded.

In its broadest sense, data base design encompasses activities that range from the identification of end-user requirements to the final management of data value on a physical device.

DATA BASE DESIGN TRADE-OFFS

The factors involved in data base design are numerous and interrelated. Consideration of all their relationships can enmesh, entwine, and even entrap the designer in a never-ending analysis without revealing the best data base configuration. To aid the data base design process, the design trade-offs inherent in this complex task need to be recognized, confronted, and evaluated.

Operational Trade-offs occur in both logical and physical design. During logical design, operational trade-offs are primarily related to strategies and tools selected for the development of the data base schema. While in the physical design phase, trade-offs involve alternatives for data base implementation.

General Trade-offs form the basis of a design philosophy that guide the formulation of implementation alternatives. These general trade-offs can be used to evaluate the feasibility of several approaches to implementation. There are five general trade-offs the data base designer must be cognizant of:

Specialization Vs. Generalization. Traditionally, file design is predicated on the needs of a specific application. Data is duplicated rather than shared, and storage and access decisions are made to optimize files for the primary user. In the data base environment, the emphasis must be placed on managing data as a corporate or leagued resource which changes the data base to a repository of shared information. This provides multiple views by multiple users of the same data whether it is physically replicated or not. Evaluating cost and performance in such an environment is complex. Care must be taken in this design decision-making.

Application and Configuration Requirements. The data base designer needs to make an economic trade-off between the power of the configuration and the requirements of the application by matching the structural and utilization requirements of the data base with the capabilities of the DBMS, access methods, and storage devices. The ultimate configuration should meet the requirements without providing significant unused capacity.

Future Planning. The design selected by the data base designer should be one that will be tenable for a number of years. He, therefore, must consider the life expectancy of the data base in conjunction with trends. New data structuring such as relational or set-theoretic data models should not be overlooked.

Planned Vs. Ad Hoc Processing. Decisions in design that lean toward planned processing put less emphasis on nonprocedural data base interaction. Ad hoc processing requires more storage overhead, more indexes and pointers, and is unnecessarily burdonsome if applications processes are known and repeated.

Extent of Required Analysis. Inefficient data base design and implementation causes severe and continuing penalties throughout the life of the DBS and, therefore, a front-end analysis is worthwhile and cost beneficial. Some degree of analysis is needed for most data bases. The depth of the analysis, however, must be weighed against its benefit.

REQUIREMENTS ANALYSIS

DMA has contracted for the performance and documentation of a Requirements Analysis (RA) for the DBS. In order to provide the systems integrators (SI's) with enough data to develop a conceptual design, the RA must provide the list and description of the global DMA functional areas requiring DBS support; the definition of the input, output, and transformation requirements for each functional area of the DBS; and the definition of the DBS support requirements such as the processing, communication, mass storage, and user interface requirements.

At a minimum, the RA will answer the following questions:

(1) Who defines/produces the data in the data base?

(2) Who controls/manages the data?

(3) How are security/privacy controls enforced?

(4) How are updating rights or restrictions enforced?

(5) How is the data base protected against inadvertent or intentional damage?

(6) How are recovery, backup, and restart from a software or hardware failure carried out?

(7) How are multiple, logical views of the same data described and maintained?

(8) Is logical or physical redundancy allowed or required?

(9) What are the existing and projected information needs of the Centers?

(10) What are the transaction flows, their volumes, responsiveness, and frequencies? (current and projected - FY 84-90)

(11) What are the application interrelationships in these flows?

(12) What are the current dependencies between major production systems (both manual and automated) and associated data?

(13) What kind of automated on-line indexes are required? (now and near future)

(14) What kind of queries are made? (related to items 10 and 11, above)

(15) What are interrelationships of files? (related to item 12, above)

(16) What are the relationships between data files and product lines?

(17) How can decentralized/on-line access be achieved?

(18) What is the effect of classification/security on the above?

The RA will be performed in a top-down manner. The final document will make maximum use of diagrams. The diagrams will define relationships of HQ DMA, HTC, AC, and outside organizations so far as general information flows and functions are concerned. Through functional decomposition and data decomposition techniques, lower and lower levels of detail will be described using diagrams and written definition. Decompositions will end with description of data elements and the input, processing, and output thereof.

REQUIREMENTS ANALYSIS METHODOLOGY

The DMA functions will be identified and described in the context of the overall DMA objectives and organization with special emphasis on organizational impacts. The information sources and projects required by each function will be identified. The location, geographically and organizationally, of each information source and product will be identified and described. Input, output, and transformation requirements of each information source and product will be described. This description will be done to a level of detail that will enable an SI to identify individual data items without implying specific aggregations that would constrain the system design.

From a global point of view, DMA functions are categorized as:

- o Receiving
  - Images
  - Maps & Charts
  - Textual Information
- o Planning
  - HQ DMA
  - Centers
  - DMA Product Preparation
- o Management
  - Headquarters
  - Centers
- o Requirements
- o Geodesy & Control
- o Image Analysis
- o Production
- o Crisis Support
- o Distribution

- o Holdings/Inventory

Having developed a list of DMA functions, each function will be described in the context of DMA's objectives and organization. The information sources and products of each function will be identified, related to an organizational unit, and described. This process will be accomplished as follows:

- o Identify the organizational units assigned to tasks related to each function.

- o Identify the outputs required of each unit for that function:

  Who has managerial/organizational responsibility?

  Who is responsible for actual documentation?

- o Identify and collect all relevant documentation for each function and task.

- o Interview relevant personnel to define the current methodology and the future requirements.

- o Produce a draft functional description of the function. Include organizational and functional diagrams.

- o Review the draft and update it with the organizational unit and other DMA management.

As each functional area is described, the individual information sources and products will be identified. The final iteration of the top-down approach is the description of these information sources and products. Each will first be related to the responsible organizational unit. Then, for each organizational unit, the following will be described:

- o Data input (content, medium, source)

- o Processing requirements (transformations)

- o Data output (content, medium, format)

- o System and environmental requirements (e.g., frequency, time responsiveness, volume, security, and integrity requirements)

The final DMA-approved RA document will be provided to the SI's for their use in the conceptual design phase. Once a conceptual design is selected and an integrator employed, the phased detailed design and implementation process will begin.

TODAY'S DMA DATA BASE ENVIRONMENT

To form a picture of DMA's data handling challenges and its current operating environment, the following data base environmental characteristics are provided:

DMA has dozens of data bases, many of which approach a rather large size of 10^{13} bytes or larger. These data bases are product-oriented, and, thus, some duplicate information and coverage. However, it must be noted that the data base schemata are reflective of product requirements and, therefore, physically redundant data items and names may be logically different as related to application, such as radio towers for cruise missile navigation from Vertical Obstruction Data and radio towers for scene simulation from DLMS. The current system is batch-oriented with very few interactive users, and processing resources are inadequate to meet the backlog of user requests. Most of DMA's digital collection systems are highly specialized, and, therefore, have limited data base abilities.

Based on the present operating scenario and production program requirements, a future forecast of the DMA operating environment can be made. Data base volume will increase. Similarly, the DMA workload, due to the expansion of data base volume, will undergo great expansion. There will be greater interdependency of data bases as well as a greater interdependency among digital products. There will be increased demands placed on DMA for more digital data to support more advanced weapons systems.

All of this being true, it is not unrealistic to see on the horizon significant problems arising from future growth. For DMA to be in an agressive posture and take advantage of new advancements and opportunities, an environment with the following characteristics must be developed:

- o A DBMS that supports a distributed, networked interactive system
- o On-line data bases with highly controlled logical redundancy to support multiple users and multiple product generation.
- o Advanced query capabilities
- o A DMA-tailored MC&G DBMS
- o Distributed, interactive access to data bases.

Furthermore, commercial developments in state-of-the-art computing and information processing power and storage technology must exponentially advance.

MC&G DATA BASE UNIQUENESS/FUTURE NEEDS

Conventional DBMS's provide data models such as relational, hierarchical, and network. These models do not totally satisfy the handling and manipulating of cartographic feature data. There do exist a few research tools (geoprocessing systems) such as POLYVRT, SYMAP, and the U.S. Census DIME files, but these systems, as efficient as they are, are limited-purpose data models for MC&G data. If one looks at how the DMA user uses the data, there is indication of what kinds of data manipulation are required. This is where the problem lies -- that is, MC&G data represents spatial information. Manipulation of spatial data is complex. Spatial functions include mathematical coordinate conversions and interpolation, transformations, distance, and direction calculations, area, shape, size, and orientation determination; adjacency, overlap, sameness, inclusion, and "betweenness" relationships among features. These spatial functions require analysis to determine algorithm derivation, data structure definition, and possibly even identification of new and/or hybrid computer architectures. Truly, much research and development (R&D) is required in this area.

In this regard, DMA R&D is investigating data base systems, management systems, data base structures, data models, and spatial functions as they relate to MC&G applications and requirements. Since the commercial sector is concentrating on the general-purpose aspects of these technologies, DMA is aiming its research at the spatial and very large data base problems. The base line for some of these R&D experiments will be the Requirements Analysis for the DMA DBS.

DMA USER MODEL

A DMA user model will be one of the fallouts of the Requirements Analysis. This model must be one that is statistical, analytical, and qualitative in order to provide information revealing the varied types of systems users, load estimations by subsystem, function frequencies, products, types of user requests, and their frequencies for each product. The user model is then a forecast of future events and decisions at all levels of design.

SUMMARY

The magnitude of this effort and its highly interrelated tasks, beginning with the definition of requirements for an interactive data base system and user and data model definitions, followed by the logical and physical designs, systems architecture and management systems, detailed data base designs and implementation, required a phased development and implementation that will span at least one-half a decade. The conversion and transition from the current system will necessitate a considerable effort in software repro-gramming to achieve the required interactive capability for DMA users. The actual execution of the conversion effort is beyond the DMA staff management, and, therefore, the systems integrator approach was taken. Aside from the complexities associated with moving from a highly structured batch processing environment to a highly interactive data base environment is the natural resistance to alteration. This aspect was best expressed by N. Machiavelli's "The Prince" (1513): "There is nothing more difficult to carry out nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things. For the reformer has enemies in all who profit by the old order, and only lukewarm defenders in all those who would profit by the new order. This lukewarmness arises partly from fear of their adversaries, who have the law in their favour, and partly from the incredulity of mankind, who do not truly believe in anything new until they have had actual experience of it."

THE GOALS OF THE NATIONAL COMMITTEE FOR DIGITAL CARTOGRAPHIC DATA STANDARDS

by

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ABSTRACT

In recent years many individuals and groups have been concerned about the lack of digital data standards in cartography for the United States. Although several efforts have attempted partial solutions to some very narrow parts of the problem no one has initiated a comprehensive effort to address the broad scope of the problem. Several months ago the National Committee for Digital Cartographic Data Standards was founded under the auspices of the American Congress on Surveying and Mapping and organized to begin the task of systematically examining the problem and issues surrounding it. This paper discusses the organization and goals of the National Committee for Digital Cartographic Data Standards and examines a number of issues associated with this work.

INTRODUCTION

Recent decades have seen a tremendous growth in digital cartography, from a laboratory curiosity to a force that dominates modern cartography. With this growth the field has seen a proliferation of differing and incompatible approaches to acquiring, coding, storing and exchanging cartographic data. It has become clear that the continuing prolifera- tion of differing approaches to the handling of cartographic data could hinder the orderly development of digital cartography. This fact has been clearly recognized and as a result the National Committee for Digital Cartographic Data Standards has been founded to address this problem. The committee operates under the auspices of the American Congress on Surveying and Mapping in cooperation with the U.S. Geologi- cal Survey and the U.S. Bureau of Standards. As discussed in an earlier paper by Moellering (1982), the committee has been given a mandate to address the question of developing standards for digital cartography. This paper discusses the organization of the committee and the goals it has defined to address the problems of digital cartographic data stand- ards.

The conceptual milieu in which the committee is operating has also expanded dramatically in recent years as noted in the earlier paper. The concepts of real and virtual maps greatly clarify the situation of the new digital cartographic products and how they relate to the more conventional products (Moellering, 1980). Transformations between real virtual maps define most important operations in cartography and have been an interesting concept for the design of modern cartographic sys- tems. Nyerges (1980) has devised the notions of deep and surface struc- ture as they apply to cartographic information and has shown that sur- face structure representations of cartographic information are real and virtual type 1 maps while cartographic deep structure is usually represented in the digital domain by type 3 virtual maps. It is also possible to look at these standards efforts in terms of deep and surface structure. Surface structure is the graphic representation of cartographic information such as a conventional map or CRT display. Over the years many principles have been defined for cartographic design which must be followed if one is to have an effective map. However, the deep structure, that area of spatial relationships between cartographic elements of cartographic information which are not graphic, is where much of the digital information resides which is stored in modern cartographic data bases. In essence, the primary task of this committee is to bring conceptual order to the area of deep structure in digital cartography.

THE WORK OF THE NATIONAL COMMITTEE

In recent years a number of ad hoc attempts have been made to define local standards for some rather narrow areas of cartography. It turns out that the groups which have attempted such efforts have done so out of necessity to implement specific tasks rather than a desire to solve a general problem in digital cartography. However, the approach of the committee is to take a comprehensive look at the field of digital cartography and attempt to devise a coordinated and general solution to the problem. The committee is composed of indivituals from the Federal, State and local agencies, private enterprise, and the university community. The current members of the Steering Committee are:

Chairman:
Prof. Harold Moellering, Ohio State University
Members:
Mr. Robert Penney, Defense Mapping Agency
Mr. Lawrence Fritz, National Ocean Survey
Dr. Richard Durfee, Oak Ridge Laboratories
Dr. Tim Nyerges, Synercom Technology
Mr. Jack Dangermond, Environmental Systems Research Institute
Dr. John Davis, Kansas Geological Survey
Dr. Paula Hagan, Analytical Sciences Corp.
Prof. Ray Boyle, University of Saskatchewan
Prof. Waldo Tobler, University of California
Prof. Dean Merchant, Ohio State University
Prof. Joel Morrison, University of Wisconsin
Observers:
Mr. Warren Schmidt, U.S. Geological Survey
Mr. Lowell Starr, U.S. Geological Survey
Mr. Henry Tom, U.S. Bureau of Standards
Mr. Roy Saltman, U.S. Bureau of Standards
Milton Goldin, U.S. Dept. of Defense
Ex Officio Members:
Mr. Ira Alexander, President, American Congress on Surveying and Mapping
Mr. Steven Vogel, President, American Cartographic Association.

Working Groups for the committee are currently being formed. The overall organization of the committee is shown in Figure 1.

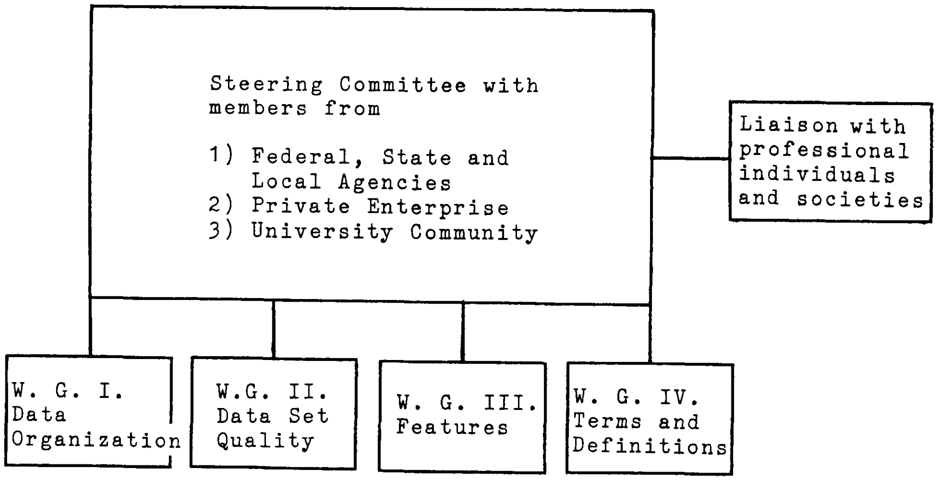

Figure 1. Organization of the National Committee for Digital Cartographic Data Standards

It has been clear to the standards committee that the primary effort of the group should focus on areas which are creating problems for digital cartography. The most pressing current problem in digital cartography is that of incompatibility between data bases in terms of data organization, feature classes and codes, coordinate accuracy, metric fidelity, content reliability, and the terms and definitions associated with all of these. Currently such specifications differ widely between data bases which can made the data interchange task extremely difficult. The payoff for the cartographic profession and user community will be that with reasonable standards in these areas, and perhaps in others later, life in our digital world can be much easier and more convenient than it is today. However, in spite of the overwhelming recognition of the need for cartographic standards, there is some concern in the community that someone might attempt to legislate certain kinds of standards which could favor one group over another. This is not the case because the overwhelming opinion of the committee is that any standards specified should be inclusionary rather than exclusionary.

At this point, it is useful to point out two proscriptions that have been defined by the committee. The scope of the committee will not include any standards relating to cartographic communication nor will it include the specification of the design of particular kinds of cartographic systems. In the first instance, it is felt that cartographic communication, although a very important area, is really outside of the realm of digital cartography as considered for the project at hand. The second proscription has been specified because efficient standards would probably be more general in some ways than those required for specific systems design, but more importantly there is a distinct feeling that one should not disturb the atmosphere which encourages innovation in this area. A third reason is that standards in the area of systems design could create proprietary problems in the private sector of the profession. The committee also has the distinct feeling that much more innovation and creative development is yet to come in cartographic systems design and specification of standards could be premature at this state of development.

WORKING GROUPS ALREADY DEFINED

The fundamental concept underlying the Working Groups (WGs) is the notion that while the broad areas of concern have been specified by the steering committee, a concerted effort should be made to identify and include the leading experts in cartography to work on the problems assigned to the WG for examination. Again, efforts will be made to maintain the balance between the Federal, State and local agencies, the private sector and academe in the membership of the WGs to the extent possible. The general goals of the WGs are as follows in Table 1.

Table 1. General Goals of the Working Groups

1) To assess the state of current knowledge and understanding in the technical area,

2) Define any gaps in such knowledge and understanding necessary to specify digital cartographic standards in that area,

3) To invite presentations and opinions from all interested parties relating to the standards area,

4) To prepare technical working papers of their deliberations and discussions, and

5) Finally, to propose digital cartographic data standards for its technical area.

The initial stage of this work concerns the enumeration of the issues which relate to the focus of each WG. As each WG proceeds through the process of specifying the important issues in its area, it has been clearly recognized that at this stage of the process it is just as important to specify gaps in our knowledge as it is to specify what we know about a potential problem. If the WGs are systematic in the investigation of gaps in current knowledge, then these findings can be collated, coordinated, and communicated to the profession as areas requiring further research on a high priority basis.

The deliberations of the committee to date have resulted in the formation of four Working Groups as shown in Table 2.

Table 2. Working Groups and their tasks

<u>I. Working Group on Data Organization</u>

1) Examine cartographic data models
2) Examine cartographic data structure
3) Examine cartographic data interchange

II. Working Group on Data Set Quality

1) Fidelity of graphical data, metric and topological
2) Coding reliability
3) Update and other temporal information
4) Lineage of a data set
5) Checking procedures used by the producer to verify quality

III. Working Group on Features

1) Define feature classes
2) Define structure and levels of classes
3) Define feature codes

IV. Working Group on Terms and Definitions

1) Collect new terms defined by working groups
2) Define other new terms

Working Group on Data Organization

The scope and goals are to identify problems in cartographic data interchange and their consequences at the operational and conceptual levels. The work should concentrate on existing data bases and data models with an emphasis on high speed transfer of, and homeomophisms between, large data bases. The WG should identify terminology and definitions of terms currently being used in the area.

It appears that the most pressing area concerns specifying common data interchange formats so that cartographic information can be converted from one data base to another. Embedded in that question is the question of cartographic data structure on which much effort has been invested, but which much more work remains to be done in the future. Embedded in that question is the question of cartographic data models. That question revolves around the situation where there are three primary data models in cartography: hierarchical, network and relational. The question is whether there exists a more general cartographic data model which could act as a covering set for the three listed above. This question is unanswered at the present time. The second question relating to data structure is the fundamental problem of converting data from one data structure to another. Although certain transformations, or homeomorphisms, between different data structures are known, many are not, and threfore how they could be specified is unclear. Advanced work on this question could help the profession greatly. The first question of data interchange at its most straightforward level boils down to data interchange formats. Many formats have been tried, and a few have seen limited use between small groups of users, but a general solution has not yet been attempted. A major thrust of this WG will be to examine the possibility of defining a small number of common interchange formats whereby one could easily convert data from one data base to another.

Working Group on Data Set Quality

When one receives a data set from some source other than ones own organization, in most cases, there are a lot of questions about data set quality which are not easily answered. For example, it is not usually known what the original data source(s) was and what scale(s) the data were gathered. It is usually not known what the original coordinate system was and to what ellipsoid they were associated. The error rates for the coding of substantive data is usually not specified, nor does one know if this data set has ever been updated. There are many attributes of a data set which should be made known to the prospective user of that data set which seem to fall into five basic categories: fidelity of graphical data, metric and topological; coding reliability; update and other temporal information; lineage of a data set; and checking procedures used by the producer to verify quality. This sort of information would be very informative to the user and indeed be very helpful in deciding whether a particular data set could successfully be used for a particular purpose. The current feeling of the committee is that what is required is that the producer provide full information about the quality of a data set for the prospective user.

Working Group on Features

When one picks a feature from some information source such as a map or air photo, there is an immediate problem of the classing system for the feature to be coded. It turns out that most agencies have feature classing schemes which are different in structure and content. These incompatibilities are complicated still further because different feature coding schemes are used. The fundamental goal of this WG is to rationalize feature classes used to specify cartographic objects and the hierarchical structure in which they are specified. A rational system of feature codes can then be specified. Specifying a consistent and comprehensive set of feature classes and codes will be a great boon to the cartographic community.

Working Group on Terms and Definitions

It is clear that these efforts will unearth terms and definitions which have not been defined in a way which is universally acceptable. Although a fair amount of work had already been expended in producing the International Cartographic Association glassaries of terms and definitions, there are many terms in numerical and analytical cartography which will be used in this effort which have not been concisely defined. The goal of this group is to systematically collect and define new terms which relate to these above areas.

Other Possible Working Groups

The above WGs have been designated as the most important because they will address problems facing the cartographic community. However, there are a number of areas which are candidates for having WGs formed at a later time. They are as follows:

1) Color - a consistent scheme for specifying color and color coordinates in a numerical form which is compatible with conventional printing would be of use to the community.

2) Geographical names - a standard set of geographical names would be useful.

3) Test data sets - if one is to have numerical and analytical procedures which are tested and verified, it seems that a common set of test data sets could be very useful.

4) Digitizing standards - these could be of use if they enhance current professional practice.

5) Digital display standards - they could be of use if they enhance current professional practice.

Other suggestions for potential Working Groups will be solicited from the cartographic community.

STRATEGIES FOR THE STANDARDS PROCESS

While defining the working groups, the steering committee has had to grapple with several knotty problems. The first is whether to use an inductive or a deductive approach to each set of tasks. Some members suggested that one should apply all known theory to the problem and work in a top down manner. Others suggested that one should begin with the operational problems and work in a bottom up mode. Each approach can be rather austere if used alone. However, if one combines both approaches and uses one to challenge the other, then there is a much higher probability that a satisfactory solution can be found. This hybrid approach is being used in all WGs and the membership of each reflects this fact.

It is clear that with the fundamental principles concerning the organization of the Committee as set forth in the second section, and with the commitment to involve the profession in these efforts of consensus building, it becomes evident that the process itself must contain a set of review cycles to solicit direct comment from the profession at large at appropriate times. It seems at the outset that the cycles will occur in the following sequence as shown in Table 3.

Table 3. Review Cycles for Developing Digital Cartographic Data Standards

1) Define the fundamental issues involved

2) Define the alternatives to the problem

3) Formulate interim proposed standards

4) Reformulate interim proposed standards

5) Generate final proposed standards

At some definite point in each of the five cycles of developing these standards, the current thinking of the WGs and the Committee as a whole will be communicated in the form of reports and position papers, and direct comments will be solicited from the profession. When the situation warrants, the relevant interface area will also be consulted. Such comments, opinions, assessments and proposals will be carefully considered by the proper WG with respect to the merits of the issues involved. This should provide sufficient opportunity for all sides to be heard.

The committee is currently in the midst of cycle one of defining the fundamental issues involved for each working group. As noted in Table 1, defining gaps in our knowledge is just as important as defining the issues themselves. This becomes evident when one realizes that in order to properly address the issues later on, one must have sufficient knowledge concerning that issue. If the committee can efficiently identify the gaps in our knowledge, then it will be possible to go to the cartographic research and funding community and present these priorities as a challenge for them to address. Hopefully this activity will focus such research efforts towards resolving such gaps in our knowledge.

SUMMARY AND CONCLUSION

With the current situation of a multitude of incompatibilities between approaches to cartographic data organization, data models, data interchange, coordinate and coding specifications, feature classes and codes, it is clear that a move towards a coordinated set of digital cartographic data standards is a step in the right direction. Although the fundamental issues are now only being defined and the major portion of the work is yet to be done, there is a prevailing sentiment that now is the time to begin the process of developing digital cartographic data standards. If efficient solutions to these problems facing the profession can be solved, then such an effort will be of lasting benefit to cartography.

ACKNOWLEDGEMENT

The work of the National Committee for Digital Cartographic Data Standarts is funded by U.S. Geological Grant #14-08-0001-G-787.

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PROPORTIONAL PRISM MAPS: A STATISTICAL MAPPING TECHNIQUE

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ABSTRACT

This paper explains a methodology for computer assisted construction of proportional prism maps. Proportional prism maps combine the design of non-contiguous proportional polygons with a three-dimensional prism map. The prism bases are formed by proportional polygons and represent one variable. The polygons are then assigned a height representative of a second variable, thus forming prisms. The map produced as a result of this research provides one solution to three persistent statistical mapping problems: 1) the problem of large, sparsely populated areas dominating the map space; 2) the limitation of displaying one set of data per map, thus restricting the reader's analytical powers; and 3) the problem of displaying two variables monochromatically.

INTRODUCTION

Most statistical maps rely upon standard land division shapes such as states or countries for a base since these shapes are often important and necessary recognition aids. One problem with statistical maps using standard land divisions as a base is that large areas displaying low values carry disproportionately heavier weight on visual perception than smaller, often denser divisions. For example, a choropleth map of the United States showing population by state shows sparsely populated, large, western states which are visually dominant over the smaller, northeastern states which become obscure in the space they occupy. This property of uneven population distribution and varying division sizes is common to statistical maps compiled at all levels (nations, states, counties, metropolitan areas), and helps to demonstrate the clustering phenomenon of geographic information (see Figure 1). This clustering phenomenon pertains to many statistical attributes in such diverse topics as politics, energy, agriculture and manufacturing, since spatial distributions are related to irregular population patterns or idiosyncrasies in the landscape. The cartographer is challenged to diminish any adverse effects that the clustering phenomenon may have on map perception.

As civilizations become more complex, the demand for displaying interrelationships between phenomena increases. The purpose of this research is to rationalize and develop a

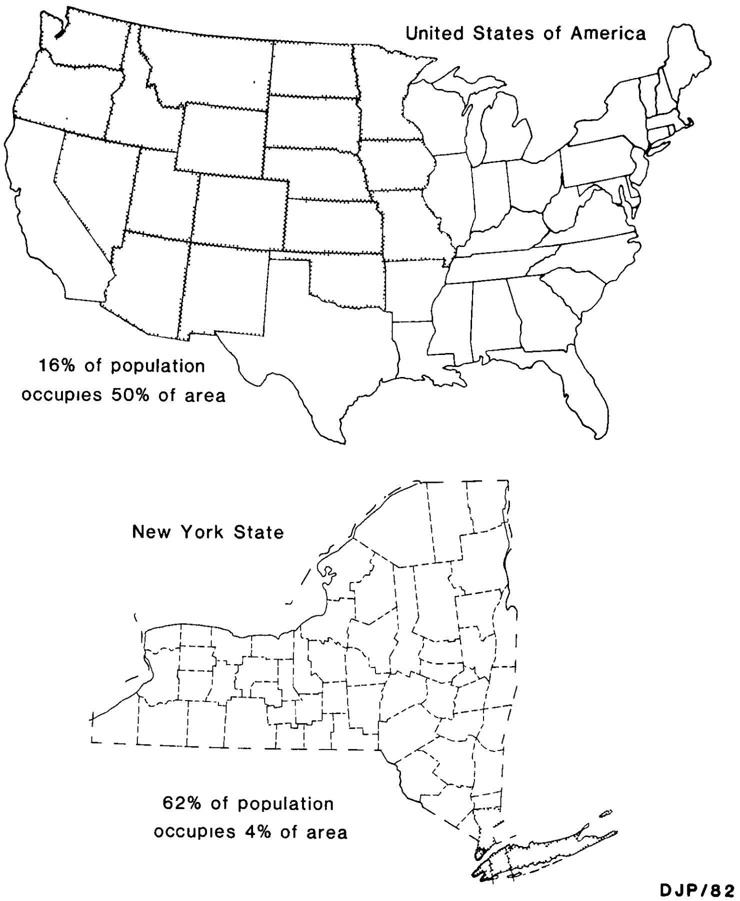

Figure 1
An example of contrasting population concentrations.

methodology for computer construction of a three-dimensional prism map with the prism bases formed by noncontiguous proportional polygons and prism heights representing a second related phenomenon. The resultant plotted maps will overcome three important statistical mapping problems: 1) the limitation of displaying one set of data per map thus restricting the analytical powers which the reader can apply; 2) the problem of large, sparsely populated areas dominating the map space and related perception problems; and 3) cartographic presentation of multiple variables in black and white. As with many types of computer maps, the sophistication of the final plotted result is governed by the amount of programming effort expended weighed against the amount of manual effort to complete a satisfactory product. Often the computer produced image should be one compilation stage towards creating a reproducible final map. Computer maps are sometimes impeded, though not stymied, in their time/cost effectiveness by demanding requirements of line widths, legend, customized labeling or shading, and lettering requirements, to mention a few. One specific time/cost consideration that pertains to a proportional prism map program is discussed in a later paragraph.

An often stated adage for novice cartographers is "keep it simple" and many cartographers adhere to this rule by displaying one theme per map using symbols or shading within area outlines. Hopefully, the result is a simple, easy to read map. However, if two phenomena are examined, a statistical relationship between the two variables is calculated and mapped, thus sacrificing the two individual sets of information for one value. Maps can display two sets of related data, utilizing such techniques as shaded proportional symbols or proportional pie shading. The drawback to reading such maps is that symbols must be read in two or more aspects and then associated with a location --- a multistep perception process. Proportional prism maps display two related variables on one map: a total population set (independent) and a subgroup of that population (dependent).

Confronting the second problem of large areas dominating the map space, proportional polygons afford one solution to the dilemma of emphasizing each area division in accordance with a particular statistical population rather than in accordance with its true area (see Figure 2). Each polygon reflects a size in proportion to its own population with respect to the total population. In addition to the primary advantage of balancing divisions by their populations, proportional polygons yield empty space around the polygon which becomes significant in showing density differences among the divisions with respect to the base unit (Olson, 1976). That is, the ratio of new polygon size to original polygon size is a measure of population density with respect to the base unit density. However, it should be noted that one problem with noncontiguous proportional polygons occurs when the base unit possesses such a high density value that many other units become small to the point of non-recognition. Therefore, base area divisions should not be too small or so dense as to force most other areas to unrecognizable smallness, but be dense enough to accommodate any potential boundary overflows.

Accepting that proportional polygons efficiently display one variable, the challenge becomes to effectively map additional parameters. Three-dimensional prism maps, where each prism base is formed by the true geographical outline of the unit area, and the height is proportional to some value, can be impressive in showing statistical information (see Figure 3). However, while eyecatching, there are shortcomings to most three-dimensional maps which must be tilted to a perspective view in order to show height dimensions. One problem is that the tilting of the plane surface to obtain the best perspective view may cause some shorter, remote prisms to be wholly or partially masked by near prisms particularly if the prisms are contiguous. In Figure 3 for example, six countries are hidden. A second problem is that the bottom

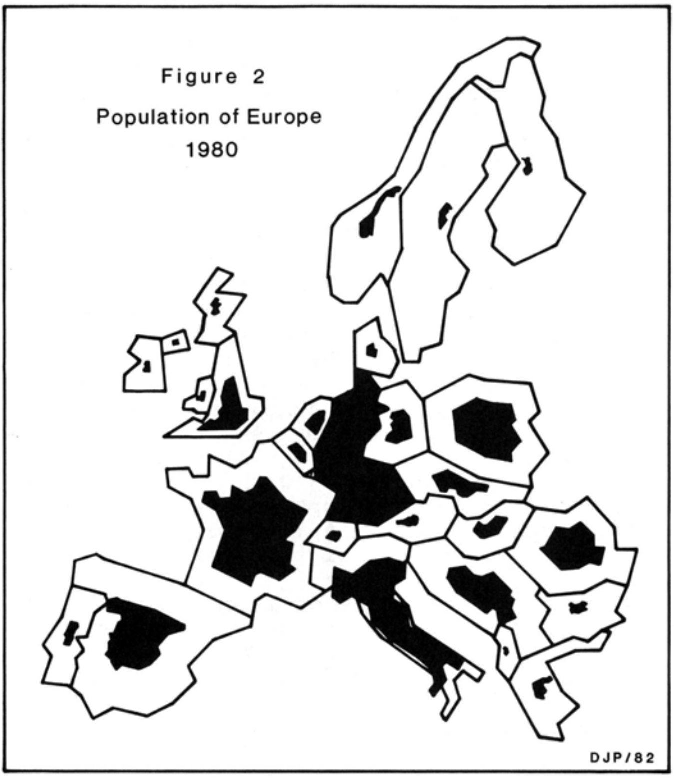
Figure 2
Population of Europe
1980
DJP/82

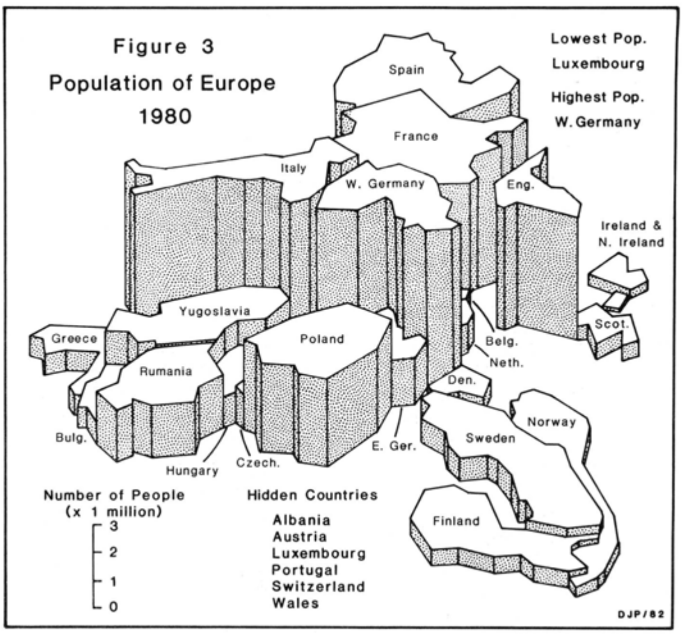
Figure 3
Population of Europe
1980
Lowest Pop.
Luxembourg
Highest Pop.
W. Germany
Spain
France
Italy
W. Germany
Eng.
Ireland &
N. Ireland
Scot.
Yugoslavia
Greece
Poland
Belg.
Neth.
Rumania
Den.
Norway
Sweden
Bulg.
E. Ger.
Hungary
Czech.
Number of People
(x 1 million)
3
2
1
0
Hidden Countries
Albania
Austria
Luxembourg
Portugal
Switzerland
Wales
Finland
DJP/82

of the prism is not always visible, making some prism height measurements more difficult. A noncontiguous proportional polygon prism map which has some open space between the prisms alleviates both of these problems. Therefore, the combination of a noncontiguous proportional polygon base and its prisms efficiently represents a total population by polygon area (x,y) and an attribute of that population by height (z). This exploits the three dimensions of the prism to show two related variables whose product is a relative quantity represented by prism volume. So while many statistical maps sacrifice actual data and display statistical relationships such as percentages, regressions, and the like, proportional prism maps present the reader with a visual relationship beyond the original input.

Limitations on multivariate mapping are also related to reproduction decisions; black and white versus the luxury of color printing. The Census Bureau's Urban Atlas series has attempted to overcome the limitations on black and white maps by employing a four by four color matrix for two variables (Olson, 1975). Unfortunately, the resulting color matrix for these maps requires sixteen color hues from three basic colors and distinction becomes difficult particularly in the middle ranges. One advantage of the proportional prism map is that three values can be readily shown solely utilizing the black and white printing capabilities of the plotter.

METHODOLOGY

To produce a three-dimensional proportional polygon map, the computer logic proceeds as follows: A base map will be defined in terms of x and y coordinates. One high valued areal division within the base map (e.g. a country) will be selected as a basis for area division values, and its prism base (base map area) will be congruent with its true outline. Within the other area divisions a polygon will be placed, factored down in size within its true area according to its population. A rectangular prism will then be formed with this polygon as its base. This prism then will contain two parallel faces which are congruent polygons. Each corresponding pair of line segments of each polygon will be connected with a rectangular face perpendicular to each polygon. The rectangular face will thus be bounded by the pair of line segments and lines connecting each segment and point with its corresponding end point on the other segment. The equal lengths of all perpendicular lines, or heights of the vertical faces, are prism heights. Each prism height is to the base prism height, as its percentage of subgroup population or its attributes value is to that of the areal division selected for the base height. A reference height is selected from the highest subgroup populations or attributes. If the height represents a percentage of total population, the prism volume then represents the total subgroup population. If the height represents a mean (average) attribute, the volume becomes the total attribute. For example, if the total population is census population, the subgroup population percentage of persons over 65 years old; then the base area of the prism is proportional to total population, the height is proportional to percentage of persons over 65, and the volume is proportional to total persons over 65. If the height is proportional to an attribute such as personal income per capita, then the volume is proportional to total personal income.

Preliminarily, the prism will be constructed orthogonally to the base map so that two congruent faces will be superimposed upon each other. The connecting lines will be merely end points. After all graduated polygon prisms are constructed, the map will be tilted by perspective projection. The resultant three-dimensional map must be oriented in such a direction that a minimum of prism surfaces is obscured; the tilt should be slight, but enough to discern heights easily. A base polygon unit will be selected upon which all other area sizes will be proportioned. The base map boundary inclusion is optional.

Production of proportional prism maps by computer requires eight major steps, each with a number of sub-tasks. In order to avoid such terms as region, area or polygon, consider a map of Europe showing total population together with number of workers in farming. The steps are:

1. Read a digital representation of Europe. A digitized equal-area projection of Europe is best. The program is capable of accepting data input in various formats and types of organizations.
2. Read data for total population and percentage of population in farming for each country. As a user option, multiple variables may be read as a matrix with rows representing countries, and columns representing different variables. This enables the user to quickly produce multiple plots. Other variables which can be supplied as designated on the control cards include the country's central point stated in x,y and the country's area. Both of these values can also be calculated by the program using the outline points.
3. Construct a proportional polygon figure for each country. Construction of the polygon requires a central base point. A desirable central point is one well within the boundaries of the figure, and situated to maximize the probability of totally containing the proportional polygon within the country boundary. Geographic centers are often satisfactory and are readily available by latitude and longitude from various sources. Ideally, a rigorous examination of the boundary in each case of size reduction should be pursued to determine the alternative possibility of using median centers, but the volume and complexity of the calculations would increase computer time extensively. Population density will be given or calculated to develop a factor for contracting the polygon within the country boundary. From all

densities calculated, a base density must be selected - the densest to guarantee contraction (no overlapping) for all countries. Areas with low values should be examined carefully in this regard. The base country density (West Germany in this case) is then assigned a contraction factor of 1.0 to designate no contraction; all other country densities are then divided by the base country density for a ratio of polygon size to state outline size.

4. Determine a height (z) for each polygon. A base height is selected as the maximum height desired for the prisms. This parameter is user supplied and a maximum percentage country must be selected by the user or by the computer to employ the maximum desired height.
5. Determine a point distribution around the perimeter of each polygon to construct vertical lines connecting the base of prisms with the top surfaces. The selection of vertical line end points is made on the basis of choosing vertical faces which will show the right and left limits of the prism and show major changes of direction in the shape of the polygon. Another criterion for choice of vertical lines can be for the purpose of shading. Equal spacing of points can cause equal shading. In order to indicate the direction of a hypothetical light source, shading can be performed on the basis of face angle from the source. Such an approach can give a realistic, three-dimensional effect.
6. Project the base maps and prisms to a three-dimensional view, given a user-defined perspective. The degree of tilt and direction of view can be user specified.
7. Remove the hidden lines and plot (Hedgley, 1982). This step in the program consumes the greatest amount of computer time. While the plot is essential, it may be plausible not to remove the hidden lines. The result will appear as a glass transparent figure with many vertical lines running through the prism. The decision here depends upon whether or not the intent is to obtain a final product, or a map for the purpose of further compilation.
8. Add appropriate descriptive information. For a finished product, title, legend, source and possibly area labels may be added. This step is also computer time dependent and some may opt for manual enhancement.

This paper presents a computer-assisted cartographic technique that combines two existing statistical mapping techniques (Nimmer, 1981), and an example is shown in Figure 4. By following the eight steps outlined above, the resulting proportional prism map should be pleasing to view if the parameters are carefully selected to minimize prism interference, to enhance interpretation of the areas and heights, and to facilitate observation unit identifications.

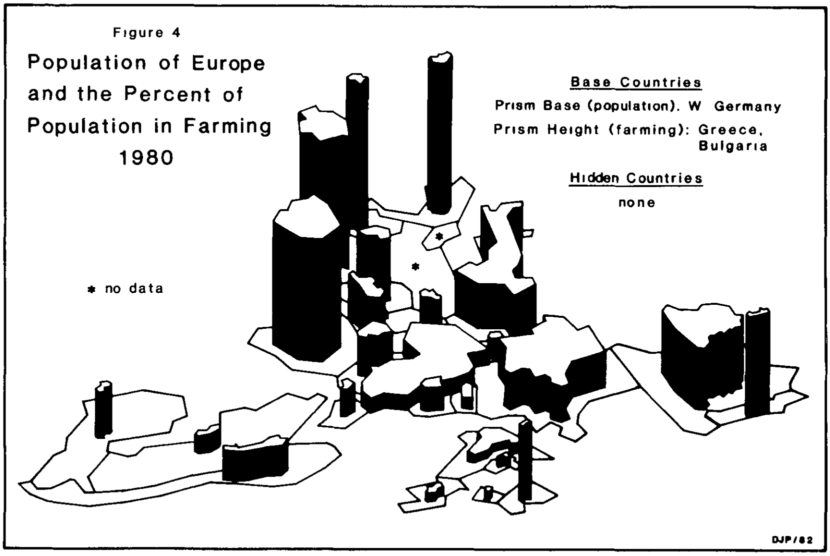

Figure 4
Population of Europe and the Percent of Population in Farming 1980

SUMMARY

There is a great need to derive cartographic techniques to display information which consist of two components. Often, the mapped variables are largely dependent on the aggregate population of which they are a part. For instance, at the global scale, gross national product is portrayed with a missing dimension. Either gross national product per capita <u>or</u> total gross national product by nation is shown, not both. The proposed mapping technique could show both and add population information by employing population as the cartogram base and gross national product per capita as the prism height. The resulting prism quantity would represent the total gross national product.

In summary, the following are considered to be major advantages and disadvantages of computer-assisted proportional prism mapping:

<u>Graphic Advantages</u>

1. The base plane viewed in perspective is more apparent since the prisms do not fill the entire plane as a traditional three-dimensional map does. This enables the reader to view the study space boundaries as well as the subdivisions.
2. Because the base plane is more apparent, prism heights are easier to see, thereby making "z" values easier to compare. The reader can see most of the tops and bottoms of the prisms since the polygons are noncontinguous, while traditional three-dimensional maps usually mask some subdivisions.
3. Proportioned polygons are easy to recognize since the shapes and locations are maintained unlike contiguous cartograms.

<u>Graphic Disadvantages</u>

1. Some base units may become so small that the polygon or prism generated may not be recognizable. Depend-

ing on the data, some units may overflow their boundaries slightly, while others remain too small.
2. Centering the proportional polygon in the base unit may not always yield the most graphically pleasing result if the unit is a complex, irregular shape.
3. Since the proportional polygon is categorically an area symbol, actual distributions are disrupted in the sense that the symbol is centralized within the base unit. The areal nature of the symbol has disadvantages similar to a choropleth map. That is, a certain amount of localized information may be lost since enumeration unit values are applied.

Computer-Assisted Advantages

1. The proportional prism map program can be interfaced with existing geographic information systems which contain a chain file and values for individual polygons (i.e. the Census Bureau's GBF-DIME).
2. The program does all calculations for polygon areas and prism heights.
3. The program generates a plot that can be incorporated into the cartographic process for refinement (line weights, prism face shading, lettering). Such manual enhancement may make the map more pleasing to view, and more reproducible.

Computer-Assisted Disadvantages

1. The routine for removing hidden lines from the polygons consumes an excessive amount of computer time since it requires a sorting procedure and external storage.

With any new cartographic technique, the question becomes whether or not the information displayed is effectively transmitted and discerned by the map reader. To date, the proportional prism map has not undergone any type of formalized perception evaluation. The maps have been scrutinized however by several geographers and computer programmers. The communication aspects of the proportional prism map have to be examined in several regards. Can the proportioned base units still be recognized by the reader as a geographic entity? How well does the map reader discern the values being represented? Can spatial relationships be realized using this mapping technique?

There is an increasing demand in statistical oriented research for effective geo-processing techniques which organize data into meaningful entities, both in tabular and graphic form. This computer-assisted proportional prism mapping program presents one approach to the challenge of visually communicating multi-variable information.

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ACQUISITION OF DATA FOR AN IRON MINING FIRM USING REMOTE SENSING TECHNIQUES FOR ESTABLISHMENT OF AN INTEGRATED STEEL PLANT

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Manila, Philippines

BIOGRAPHICAL SKETCH

This Biographical Note is being presented for the purpose of bringing out the author's background in Digital Photogrammetry and Remote Sensing. As an author of numerous technical papers both in the American Society of Photogrammetry and Remote Sensing Centers such as Eros Data Center and the Environmental Research Institute of Michigan(ERIM) and closely related to this event the author is affiliated to the NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) at Washington,D.C. under (MLA) Remote Sensing Program - Management and has greatly contributed to the United Nations University in Tokyo,Japan in the development and management of natural resources, such as held by the (ERIM) and (NRMC) on 20-26 APRIL ,1978 Manila,Philippines the 12th International Symposium on Remote Sensing of Environment.

ABSTRACT

In the decades to come, Remote Sensing uses will be very important in locating various important geological structure in wider regional scales as used in this paper.

1.-. Landsat-D rectification using additional bands; The seven (7) channel Multispectral scanner called the Thematic Mapper (TM):

1.1. Channel 1-0.45 - 0.52 µm

- visible Blue Green.

2.1. Channel 2-0.52 - 0.60 µm

- VISIBLE RED

e.i.

3.1.· Band 5, the red band,0.6 to 0.7 micrometers, emphasizes cultural features, such as metropolitan areas.

4.1. Channel 4 -0.76 - 0.90 μm
- INVISIBLE SOLAR INFRARED *

e. i.

Band 7, the second infrared(near-) band 0.8 to 1.1 micrometers provides the best penetration of atmospheric haze and also emphasizes vegetation, the boundary between land and water, and landforms.

5.1. Channel 5- 1.55 - 1.75 μm
INVISIBLE SOLAR INFRARED

6.1. (Channel 6) 2.08 - 2.35 μm
(SOLAR INFRARED)

7.1. Channel 7 - 10.4-12.5 μm
THERMAL INFRARED

2.- WE HAVE USED THE FOLLOWING COMPUTATIONS FOR THE KEY TO MAKE THERMAL ENERGY YIELD ESTIMATES:

$$E_{th} = V\sigma (TC + \beta) J \text{ ** } \quad (1)$$

Where: Eth= Thermal Energy yield in ergs/sec (assuming) cooling to ambient temperatures,--- (2)

V= Volume of extrusive lavas in cm^3/sec,------ (3)

σ= mean density of extrusive lava in g/cm^3 ------------------------------------ (4)

T= maximum temperature (above ambient) of lava, in °C. ------------------------------ (5)

C= specific heat of lava -------------------- (6)

β= latent heat of lava, and ----------------- (7)

J= equivalent work of heat (4.1855×10^7)---- (8)

* Originally published in Sioux Falls, South Dakota United States Department of the Interior Geological Survey, pp. 70-71

The areal pixel of the geological remote sensing work being done is located at the Pacific Ocean Basin (Philippine - Trench), South East Asian North of the Philippines.

INTRODUCTION

At the present decade, through precise and accurate measurements such as Digital Photogrammetry and Remote Sensing techniques can accomphlised, the Gabun-Paracale Mining Co., Inc. an Iron Mining Firm has more consistency in ores deposition using (Satellite Photograph as in Figure I) to bring about regional deposits for the establishment of an Integrated Steel Plant and quantification by mathematical geomorphological estimates of its raw materials like iron-ore, coal, and limestone in nearby regional raw materials are set up as in a Nodal Point(Central Part) as general estimates herein are made by Digital Photogrammetry and Remote Sensing.

GEOLOGICAL REMOTE SENSING SAMPLING THROUGH MATRIX ALGEBRAIC EXPRESSIONS

Plant and Mines Site Surveying

We have used here definite position of Plant and Mines Site through Satellite Datas, Flight Datas, and Ground Work follow-ups in order to set-up definite different plant locations and raw materials locations of Mines Site.

Let $X^4\ y$ = Plant and Mines Site------- (1)

Y(Angle of Pitch)=Geomorphic Rocks------------ (2)

X^4(Ore Shoots)=Pod-Like viens of known mineral resources regional values.------- (3)

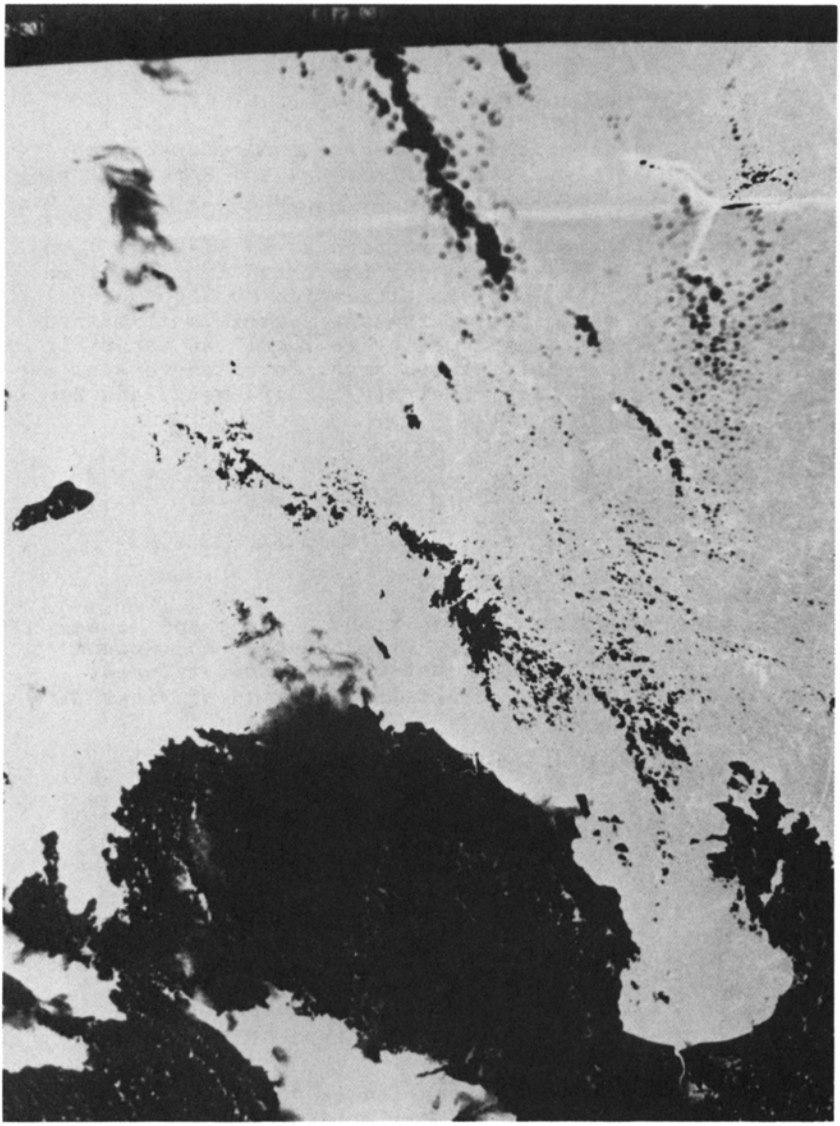
Y^3(Regional Ecology)= Geomorphological type of rocks--- (4)

$X^6\ \tilde{N}$ = Vien-Like lenses of structural origin------------ (5)

LET $X^4\ Y = X^6\ \tilde{N}y + X^4\ y^3$-------------- (6)

** Original publication in Falls Church, VIRGINIA by the AMERICAN SOCIETY OF PHOTOGRAMMETRY,pps. 1208-1209

SATELLITE PHOTOGRAPH NO.1



F I G U R E - 1

TO BRING ABOUT REGIONAL DEPOSITS FOR THE ESTABLISHMENT OF AN INTEGRATED STEEL PLANT.

DIGITAL PHOTOGRAMMETRY AND REMOTE SENSING DATA AS USED IN AQUISITION FOR INTEGRATED PLANT SET-UP

Morever, pertinent information for user data is made by a formal acquisition and using a Nodal Point(See Satellite Photograph as in Figure 2) this is important in Digital Photogrammetry and Remote Sensing especially in setting up an Integrated Plant in -Situ. In nodality an ecological balance of raw materials can be attained by the user.

Digital Photogrammetry and Remote Sensing Data for Plant and Mines Site

In the earlier decades of resource managers, cartographic analysis, photogeologist, photointerpreters a wider mosaic scaling has been established by satellite photographs, aerial photographs and groundwork follow-ups. More than ever before this important aspects should be followed in acquisition of data through Digital Photogrammetry and Remote Sensing:

1.1. The Approach

2.2. The Management of Resources

3.3. The Technical Side

Regional Ecology

And in a more logical manner of presenting to the would be user is the regional ecology of the raw materials is highly considered in the turn of this century as explained in (DIAGRAM A) :

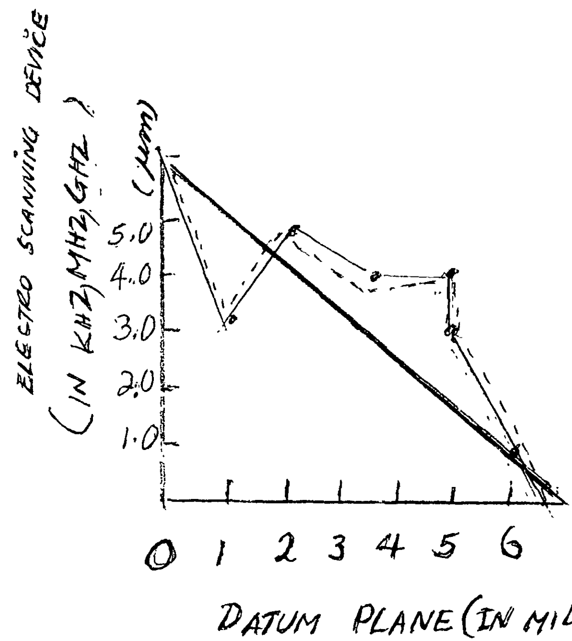
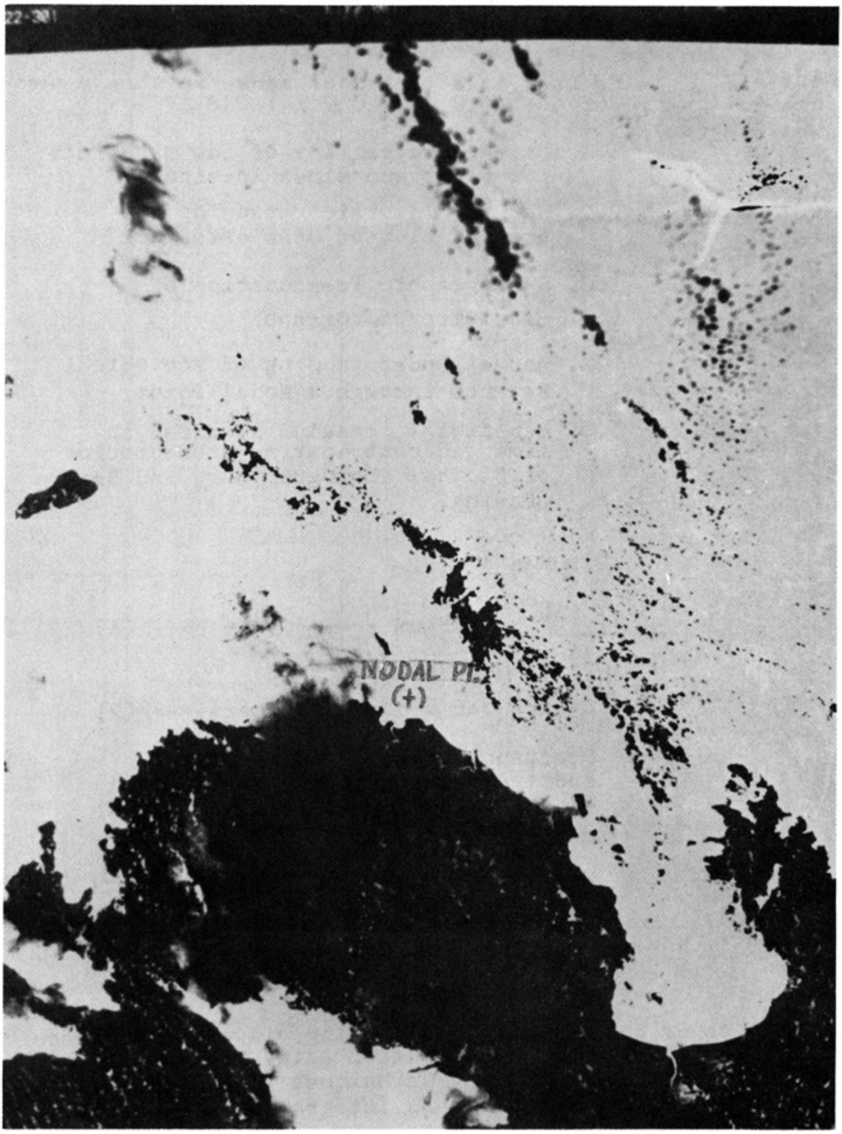


Diagram A
(Dr. NAVARRO, A.A.)
Effect of usage of geological remote sensing in ORES solar reflectance in percentage angle.

SATELLITE PHOTOGRAPH NO.2



F I G U R E – 2

DIGITAL PHOTOGRAMMETRY AND REMOTE SENSING DATA
THROUGH THE USE OF A NODAL POINT. (+)

RELEVANT USES OF DIGITAL PHOTOGRAMMETRY AND REMOTE SENSING IN THIS IMPORTANT DECADE FOR GENERAL NODALITY

Generally, as being used in a technical sense in this paper is the following for the AUTO -CARTO V / ISPRS IV :
(See Diagram B)

1.1. Linear Programming of raw materials for plant and mines in-situ.

2.2. Matrix Algebraic reasoning of presentation of user data.

3.3. Cartographic Presentation of Satellite Photograph.

4.4. Actual understanding of ecological balance through a Nodal Point.

5.5. Beneficial results acquired in time and contributing presentation of Digital Photogrammetry and Remote Sensing.

DIAGRAM B

$$\lambda = \frac{3 \times 10^8}{10^{15}} = 3 \mu m \text{ ---------------- } (1)$$

3×10^8 = Cycles per second in meters-----(2)

10^{15} = Frequency Level
and (visible portion)
of EMR (ELECTROMAGNETIC RADIATION)
or commonly known as POLARIZATION
of EMR------------------------ (3)

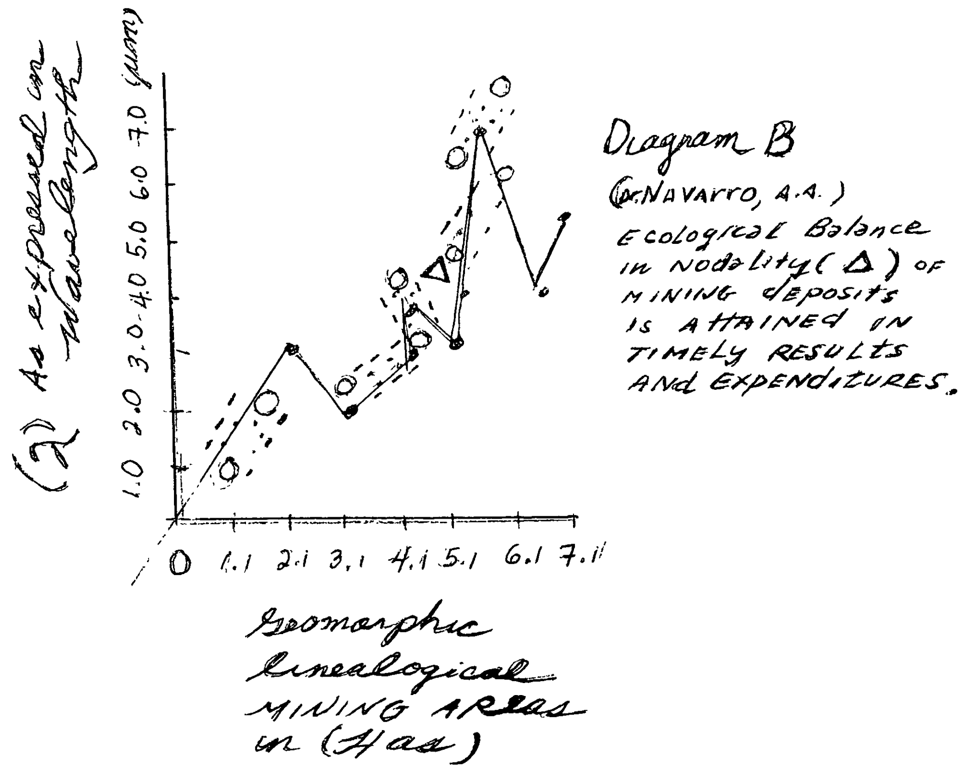
λ = WAVELENGTH ------------------- (4)

CONCLUSION

In this paper the NODAL POINT is being viewed as a source of information for Data Acquisition using Digital Photogrammetry and Remote Sensing Techniques for an Iron Mining Firm in the establishment of an Integrated Steel Plant.

A NOTE OF APPRECIATION

My heartfelt thanks to the Remote Sensing Community and to the International Photogrammetrists who in one way or another have made special efforts in making it possible for me in presenting this paper and have share their undying faith in contributing their time and effort to the author.


(λ) As expressed in Wavelength
1.0 2.0 3.0 4.0 5.0 6.0 7.0 (μm)
0 1.1 2.1 3.1 4.1 5.1 6.1 7.1
Geomorphic Linealogical MINING AREAS in (Has)
Diagram B
(Dr. NAVARRO, A.A.)
ECOLOGICAL Balance in Nodality (Δ) of MINING deposits is attained in TIMELY RESULTS And EXPENDITURES.

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GEOGRAPHIC NAMES INFORMATION SYSTEM: AN AUTOMATED PROCEDURE OF DATA VERIFICATION

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ABSTRACT

The U.S. Geological Survey has researched and developed an automated geographic names data base to help meet national needs and to provide informational and technical assistance to its mapping program. The Geographic Names Information System (GNIS) is currently capable of providing data for approximately two million names and their related features in the United States and its territories. Cartographers can retrieve, manipulate, and organize name information to meet many mapmaking requirements. An automated mapping procedure has been developed to verify data submitted during the initial compilation of GNIS. This procedure has been expanded to assist the new provisional mapping program of the USGS, and it has proven to be valuable preliminary research for a program of automated typesetting and name placement. Also, research is being conducted toward the eventual incorporation of information from the System into the Survey's Digital Cartographic Data Base.

INTRODUCTION

The Geographic Names Information System (GNIS) is a multipurpose data system designed to meet major national needs. Versatility is a basic tenet in the design of the system which affords great utility to a wide variety of users. Users may be grouped into two categories: (1) those who use the information directly for research or reference, and (2) those who reformat retrieved data for individual or specialized use. Information from the system may be retrieved, manipulated, analyzed, and organized to meet the general or specialized needs of a wide variety of users involved in research or application. There are currently five data bases in the system:

(1) Geographic Names Data Base
(2) Topographic Maps Data Base
(3) Designator/Generic Data Base
(4) National Atlas Data Base
(5) Board on Geographic Names* Decisions Data Base.

This paper will refer to the Geographic Names Data Base throughout. The purpose of this paper is to provide an overview of the development of the Geographic Names Data

*The U.S. Board on Geographic Names was created in 1890 and established in its present form by Public Law in 1947, and is authorized to establish and maintain uniform geographic name usage throughout the Federal Government.

Base, to describe the method used to verify the data compiled from U.S. Geological Survey topographic maps, and to identify and project some cartographic applications of the Geographic Names Data Base.

DATA BASE DEVELOPMENT

Research and initial compilation of GNIS was begun in 1968. GNIS data were collected as time permitted, resulting in the completion of data compilation of geographic names for the Commonwealth of Massachusetts and the State of Rhode Island as well as the automation of the data embodied within U.S. Geological Survey Professional Paper 567, The Dictionary of Alaska Place Names (Orth, 1967). In 1976 the geographic names in Kansas and Colorado were compiled and verified as a pilot project to determine the feasibility of compilation on a national scale. After analysis and a favorable evaluation of this pilot project, name data for the remaining States and territories were compiled from 1978 through 1981. This period of initial compilation is referred to as Phase One, consisting of the input to the data base of all geographic names and related information found on the U.S. Geological Survey's 7.5-minute topographic map series except roads and highways, communication towers, and triangulation stations. The 7.5-minute series was used because it was the largest scale available. In the absence of published 7.5-minute maps, 15-minute, 1:62,500-scale topographic maps were utilized, and when there was no coverage by either scale, the 1:250,000-scale topographic maps were used. Compilation of geographic names and attribute information was completed by a private contractor and the collected data were delivered to the Geological Survey on magnetic tape on a State-by-State basis. Geographic coordinates of named features were digitized to the nearest second of latitude and longitude. Coordinates were taken at the center of areal features and the mouth of linear features and were called primary coordinates.

If a feature was not contained entirely within the bounds of one map geographic coordinates (called secondary coordinates) were also digitized at some point on or along the feature for every map through which the feature passed. Other attribute information such as feature class, county, elevation, and map was keyed from annotated topographic maps directly to a magnetic disk.

METHOD OF DATA VERIFICATION

To ensure the integrity of data received from the contractor, names contained on 10 percent of the 7.5-minute maps used in compilation were verified. Data verification required the retrieval of names and their attributes from the data base for direct comparison to the 7.5-minute topographic map.

Comparing name information contained in the data base in the form of a computer printout can be a time consuming process, mostly by time spent locating the name on the appropriate map and computing the geographic coordinate by hand for comparison with the digitized coordinate appearing in the printout. To minimize the time spent in this vital process, a form of automated name placement was used based upon the location of the feature according to the digitized geographic coordinates and relative to the position on the particular 7.5-minute map.

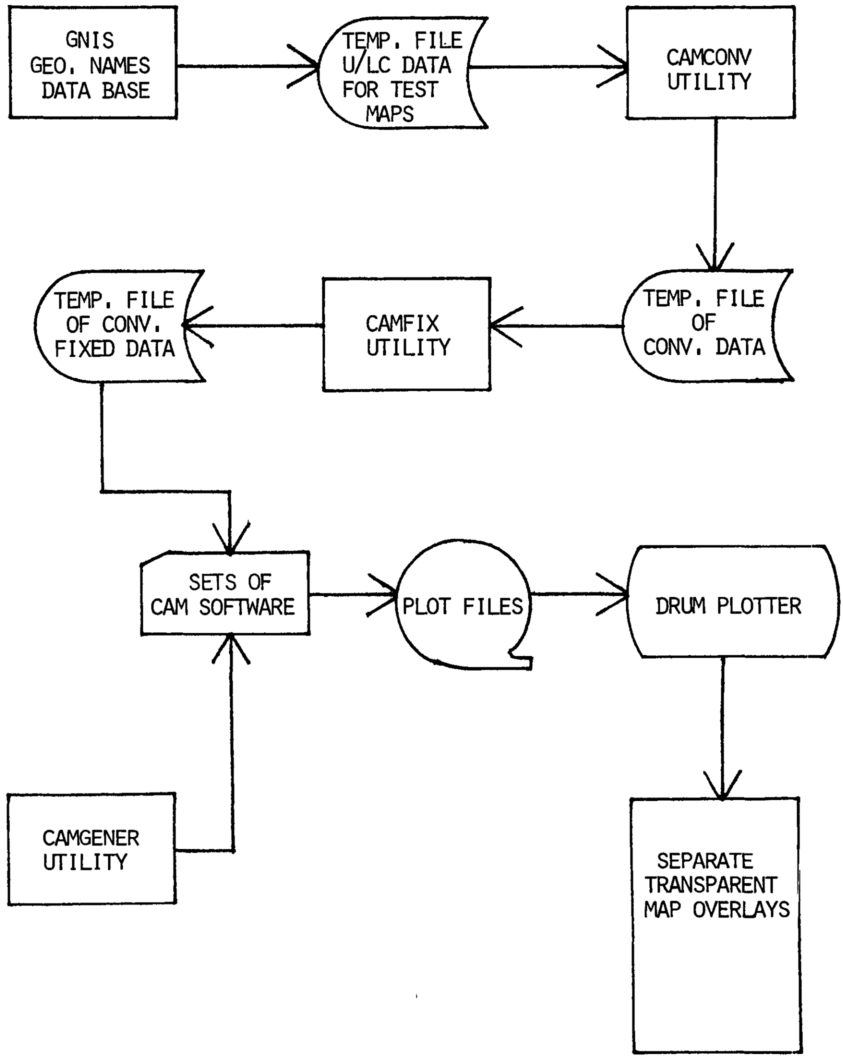
The automated name placement was accomplished through the use of the Computer Automated Mapping (CAM) software package. Although CAM is designed to be most effective when used at smaller scales, its use in plotting point data is also accurate at the scales of 1:24,000 and 1:62,500. Using the digitized coordinates as input to CAM, a selected symbol (*) was plotted to indentify the primary coordinates of each feature on a transparent map overlay while a different symbol (Ø) was used to indicate the source of linear features.

A computer program was written to generate individual sets of CAM software peculiar to the maps selected for sampling. The southeast corner coordinate of the desired maps were supplied and the utility software generated the necessary center point, boundary coordinates, map projection, and other individual map information required by CAM to produce the transparent map overlay.

The data base was then queried using the GNIS data base management system and data were retrieved for the sampled topographic maps and written as one temporary data file. The selected GNIS data were then passed through utility software to convert the name information from upper/lowercase to all uppercase. This conversion was necessary because the available version of CAM could utilize only uppercase information. The previously generated CAM software was used to select data from the temporary file according to map specifications and generate sequential files on a magnetic tape for each map selected. Any number of tapes may be generated simultaneously using this process. The resulting plot tapes contained plotting information and geographic name data for the sampled maps. A flow diagram of the data verification procedure is shown in Figure 1.

IMPLEMENTATION OF THE VERIFICATION PROCEDURE

A separate map overlay plot for each map selected for testing was generated on the drum plotter. The transparent map overlay with the plotted information was then laid directly over the corresponding 1:24,000- or 1:62,500-scale map. The researcher could locate the named feature at a glance because the geographic name was plotted directly beside the symbol where the digitized geographic coordinate of the feature was plotted. One could then determine by the placement of the symbol if the digitized coordinates were correct or within the accepted tolerance of ±5 seconds of latitude or longitude. In this fashion the laborious



CAMGENER:	Generates sets of complete CAM software for individual test maps.
CAMCONV:	Generates all uppercase data from upper/lowercase data because CAM requires uppercase data.
CAMFIX:	Moves the printing of geographic names to avoid overprinting--does not move the symbol which indicates the actual point of the digitized coordinate.

Figure 1.--The automated data verification procedure, which may be accomplished simultaneously for any number of tapes.

task of locating the name on the map was minimized. An accompanying printout allowed other attribute information to be verified.

Often, a particular area or section of a topographic map would have a dense pattern of geographic names even at the large scales being used. The problem of overprinting of geographic names required additional attention because the available version of CAM could not test for overprinting. To increase the utility of the verification process, software was developed to overcome this problem. The area within ± 2 seconds of latitude and the area within 15 seconds of longitude was tested for overprinting. If the printing of two or more geographic names were found to be in conflict then the printing of the names was moved ± 3 seconds of latitude. There was no longitudinal shift. The placement of the symbol remained at its exact location. This procedure was effective in almost all instances and allowed for increased readability and continued efficiency in locating the named feature. The overprinting utility was the last operation performed on the selected data before input to CAM.

For the purpose of accepting data supplied by the contractor, a weighted point system for all possible errors was developed. Each plotted map was scored according to the weighted point system and the number of error points was calculated against the total number of names on the map. In order to be acceptable, the error rate per map could not exceed 5 percent.

ADDITIONAL APPLICATIONS

Elements of this geographic name data verification procedure are being used by the U.S. Geological Survey's National Mapping Division to assist in its mapping program. One application is the use of transparent map overlays of geographic names data as guides in field research of geographic names. Also, subsets of the names data may be retrieved for specific applications; one may wish to plot only the names of streams or often only names that required action by the U.S. Board on Geographic Names. An additional option is being incorporated into the procedure. While not necessary for testing the validity of contractor data, some researchers have expressed an interest in plotting secondary geographic coordinates. Software is being developed to incorporate secondary coordinates into the plotting procedure. This will allow researchers to visualize the general trend or scope of large features.

Phase Two of the development of the data base includes inputting to the system names and related information found on all available source maps and texts, but not recorded on USGS topographic maps. Phase Two compilation is complete for the States of New Jersey and Delaware. As more States complete Phase Two compilation the map overlays resulting from the verification process will be invaluable in determining names for features in areas not mapped in great detail.

The procedures developed for testing the validity of GNIS data have proven worthwhile as a preliminary tool in the National Mapping Division's current research into automated name placement. Research is also being conducted toward the compatibility of GNIS information with that of the Digital Cartographic Data Base for eventual incorporation of selected GNIS data.

SUMMARY

The initial compilation of the geographic names data base required a completely automated procedure for verifying geographic names data digitized by a private contractor. The volume and nature of the data required the concatenation of utility programs with GNIS and CAM in order to automate the complex procedure required to verify the data. The products were transparent overlays containing symbols at the point where the primary geographic coordinates were digitized and the geographic name printed beside the symbol. The use of transparent map overlays provided for rapid and efficient location of the named feature with absolute verification of the coordinates, and the accompanying printout provided verification of attribute data. The procedure developed for testing geographic names data has provided valuable research and assistance in the development of automated name placement and has identified some possible compatibility problems in incorporating geographic names data into the Digital Cartographic Data Base.

FORPLAN PLOTTING SYSTEM
(FORPLOT)

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ABSTRACT

The National Forest Management Act (NFMA) of 1976 requires the Forest Service to carry out integrated planning on all National Forest System lands. Resource planning includes three areas of interest: land allocation, output scheduling, and spatial analysis. The main tool for allocation and scheduling is the Forest Planning Model (FORPLAN), primarily a linear programming model. Its outputs are used in determining how specific management practices should be applied to an area in order to best utilize available resources.

The purpose of the FORPLOT mapping system is to produce map overlays showing FORPLAN-assigned prescription labels (labels indicating how Forest areas should be used) in a user-specified area. By placing FORPLOT-generated overlays over topographical maps, Forest Service land use planners can quickly and easily ascertain how to manage a given section of the Forest (according to the FORPLAN linear programming model).

Each Forest area is broken down into analysis areas consisting of one or more noncontiguous Forest sections possessing similar characteristics. Each analysis area section is called a "polygon" and is labeled according to FORPLAN-assigned management descriptors (prescription labels).

FORPLOT merges a data file containing FORPLAN-assigned prescription labels with a data file containing the geographic coordinates for analysis areas and their associated polygons. FORPLOT then produces a data file containing both prescription labels and the locations where those labels should appear on the map. Map overlays are then produced on either a line printer or a plotting device such as a drum plotter.

BACKGROUND

Prior to the National Forest Management Act of 1976 (NFMA) the different specialists on the National Forests went about their planning efforts almost independently of one another. Timber Management Specialists had developed some harvest scheduling systems to aid them in their planning. Land Management Planning Specialists had come up with various linear programming formulations and structures to do their unit plans. The other specialists had their own analytical tools, but there was no single controlled effort to perform integrated planning. NFMA changed all that and required the Forest Service to conduct integrated planning on all the national forest lands. There were several approaches that were being proposed to perform the planning analysis. In reviewing existing programs, it was determined that they could be modified to handle most of the analytical approaches that were needed. As a result, the FORPLAN system had its origin from these existing programs.

FORPLAN System. FORPLAN is a computerized forest planning system to aid land managers in their decision making process. The FORPLAN system consists of a matrix generator, a linear programming (LP) algorithm, and a report writer. The matrix generator generates a matrix of scheduling activities and the linkages required to combine the two individual matrices into one for solving. The matrix for the allocation portion of the problem must be generated by user-developed generators. The LP algorithm is derived from UNIVAC's Functional Mathematical Programming System (FMPS). The report writer is the most important part of the system for the land manager. It interprets the solution which comes out of the LP algorithm and generates a series of tables and graphs which depicts where (in a general sense), when, and how much land is required to meet the targets or objectives. It also produces the output file containing the descriptive data necessary for input to FORPLOT.

FORPLAN PLOTTING SYSTEM (FORPLOT)

Overview. With the adoption of FORPLAN as the primary tool for resource planning and utilization, there developed a need to gain a spatial insight as an additional tool in the process of allocating forest resources. This can be accomplished by an overlay upon which the FORPLAN solution set can be drawn. The purpose of FORPLOT is to produce map overlays showing FORPLAN assigned prescription labels in a user specified area. By placing the FORPLOT generated overlays over topographical maps, Forest Service land use planners can quickly and easily ascertain how to manage a given section of the forest according to the FORPLAN LP solution.

Each forest area is broken down into Analysis areas (AA) which consist of one or more Capability areas (CA). Each CA of an AA is referred to as a polygon. These polygons are labeled according to the management descriptors (prescription labels) assigned by FORPLAN.

CA's are defined as the smallest homogeneous land area used to describe characteristics of the land and resources in an integrated forest plan and are delineated using established Forest Service guidelines. AA's consist of contiguous and non-contiguous CA's combined for the purpose of analysis in formulating alternatives and estimating impact and effects.

FORPLOT merges a data file containing FORPLAN assigned prescription labels with a data file containing geographic coordinate pointers for AA's and their associated polygons (AA file). FORPLOT then produces a data file containing both prescription labels and the location where those labels should appear on the map. The map overlays can be produced on either a line printer or a plotting device such as a drum plotter.

The FORPLOT mapping system is made up of three separate programs: FORPLOT, PTPLOT, and DPPLOT. FORPLOT is the program which merges the FORPLAN file and AA file, prepares the label plot file, and produces printed reports. PTPLOT is the program which generates a printed map overlay and DPPLOT is the program which produces map overlays on a specified plotting device. Figure 1 is a general flow diagram that depicts the FORPLOT mapping system.

FORPLOT Program. FORPLOT is the main program of the FORPLOT mapping system. It is used to generate the label plot file, which contains polygon coordinates prescription labels and/or indexes where applicable. Indexes are generated in place of prescription labels if there are too many labels assigned to a single position, if labels from one polygon will overlap those of another, or the area of a polygon is smaller than the minimum area that can be labeled.

Input. There are two types of input entered to run the FORPLOT program, required parameters and optional parameters. Required parameters include a file containing the FORPLAN produced prescription labels, a file containing the geographic coordinates of a point within each polygon, the name of the file to which the label plot records are to be written, and values to define the area to be mapped. Optional parameters include values to be used in scaling the map, the character size of the prescription labels and indexes, the minimum size a polygon may be in order to be labeled on the map, the maximum number of prescription labels that can appear over any one polygon, special character codes, and names of the files in which the printed report and error messages are to be placed.

Output. Output generated by the FORPLOT program are the label plot file containing the labels and indexes that are to appear on the map (and their locations on the map), the parameters entered during the session, computerd values used to produce the map, and a printed report. The report consists of four parts; a list of the parameters entered or computed during the session (Figure 2), a Dictionary Report listing the prescription labels on the map (Figure 3), a Prescription List (PLIST) listing all the indexes on the map and prescription labels that would have been printed in place of the indexes (Figure 4), and a Coordinate List (CLIST) listing the coordinates, in map inches, of prescription labels that could neither be plotted or indexed on the map (Figure 5).

FORPLOT GENERAL FLOW CHART

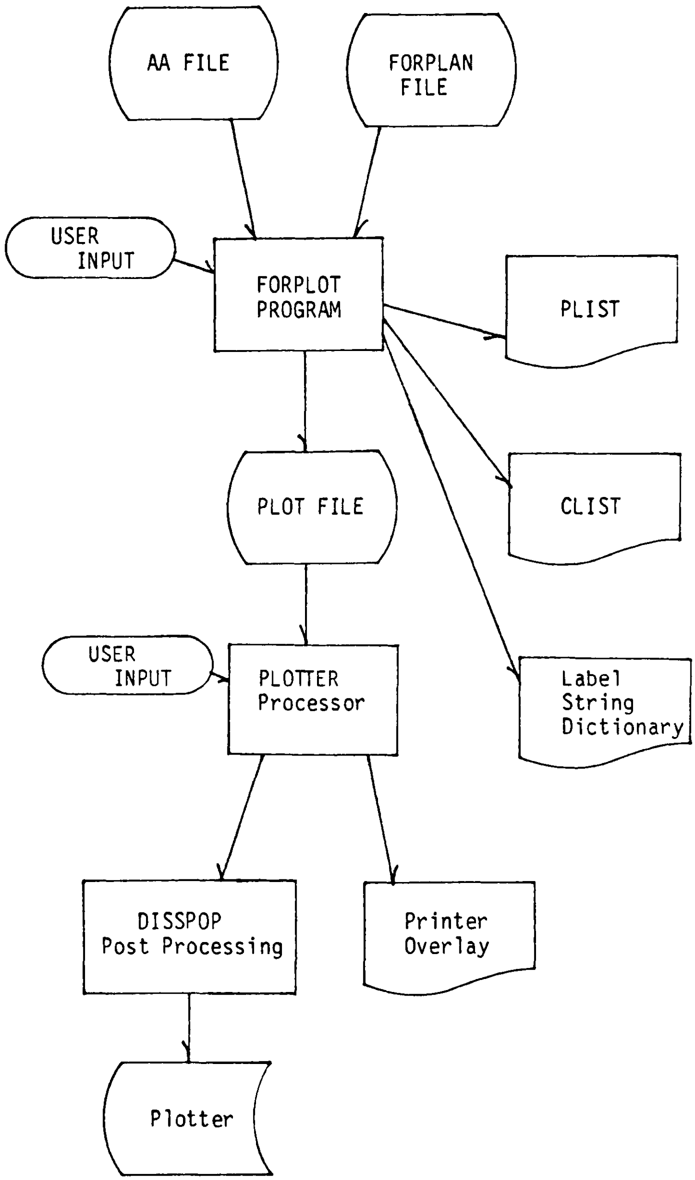

Figure 1

PTPLOT Program. PTPLOT is the program which produces map overlays on a high speed line printer or printing terminal. It generates the prescription label map overlay, using data obtained from the label plot file. The output generated by this program is a line printer map overlay (Figure 6).

DPPLOT Program. DPPLOT is the program which produces map overlays on a specified graphic output device. The output devices on which map overlays can be directly produced are; Tektronix 4010 Series terminals, Zeta plotters, and Hewlett-Packard 7221 plotters. Additionally, DPPLOT can produce a file which can be used by a preprocessor program to produce map overlays on additional graphic output devices. DPPLOT generates a map overlay by using the data in the label plot file.

Input. DPPLOT also uses both required and optional parameters to input data and map specifications. The required parameters must be the filename of the label plot file generated by the FORPLOT program. Optional parameters include the name of the graphic output device on which the plot is to be produced, and various parameters to define the exact way the map overlay is to appear.

Ouput. The output generated by the program is a plotted map overlay (Figure 7), or a file which can be sent to a post-processor for later plotting on other graphic output devices supported by the USDA Fort Collins Computer Center, located at Fort Collins, CO.

CONCLUSION

FORPLOT is designed to produce map overlays showing FORPLAN assigned prescription labels in a user-specified area. These overlays are plotted quickly and automatically. The planner can then visually determine the feasibility of a FORPLAN solution and make the appropriater allocations of land to meet Forest Service resource planning objectives.

REFERENCES

_____1981, FORPLAN Mapping System (FORPLOT) User Manual, USDA Forest Service

_____1981, FORPLAN User's Manual, USDA Forest Service

```
F O R P L O T   P R O G R A M                             VERSION - 10/1/81

US FOREST SERVICE                                         * * * * * * * * * *
DATE:  OCT 20, 1981                                       *  F O R P L O T  *
TIME:  11/50/20                                           * * * * * * * * * *



                INPUT PARAMETER LIST

TITLE:  SAMPLE MAP USED FOR RUN COST ESTIMATES
FORPLOT FILE:  LMP*PLOTF.
AA FILE:       LMP*AAQUAD.
PLOT FILE:     LABFILE.

     5000.000 = XSCALE              5000.000 = YSCALE
       39.850 = SW LAT               105.870 = SW LONG
       39.921 = NE LAT               105.800 = NE LONG
         .100 = XCELL                   .167 = YCELL
       -1.000 = ACRES                  3     = NOP


                  RUN STATISTICS

           38 = NUMBER OF POLYGON RECORDS IN AA FILE
           38 = NUMBER OF POLYGONS WITHIN MAP WINDOW
           39 = NUMBER OF ANALYSIS AREAS IN MAP WINDOW
            5 = NUMBER OF ANALYSIS AREAS NOT IN FORPLAN
           31 = NUMBER OF LABELED POLYGONS
            3 = NUMBER OF INDEXED POLYGONS (MAY BE LABELED)
            6 = NUMBER OF POLYGONS NOT LABELED/INDEXED (IN CLIST)
           70 = NUMBER OF DICTIONARY ENTRIES

        4.000 = MAP LENGTH                  5.17 = MAP HEIGHT

AA FILE HEADER:  DATA SUPPLIED BY GEOMETRONICS DIVISION, U.S.F.S.



NOTE:  ONLY THE FIRST ACTIVE TIME PERIOD IS SELECTED FOR EACH PRESCRIPTION.
```

FIGURE 2

PRESCRIPTION LABEL DICTIONARY

TYPE E = MANAGEMENT EMPHASIS
TYPE I = MANAGEMENT INTENSITY

TYPE	VALUE	MANAGEMENT DESCRIPTOR
E	1	MINLVL
E	2	GENFOR
E	3	SC/REC
E	4	SP INT
E	5	UR REC
E	6	W-SDMA
E	7	W-WINT
E	8	W-DIVR
E	9	W-SMU
E	A	WILDER
E	B	NO URB
I	!	54
I	"	39
I	$	48
I	#	51
I	&	47
I	'	57
I	(	50
I	)	41
I	*	49
I	+	43
I	,	55
I	-	42
I	/	59
I	0	1
I	1	2
I	2	3
I	3	4
I	4	5
I	5	6
I	6	7
I	7	8
I	8	9
I	9	10
I	:	52
I	;	58
I	<	44
I	=	45
I	>	46

FIGURE 3

PLIST - PRESCRIPTION LIST

INDEX	AAID	POLYGON ID	POLYGON AREA (ACRES)	* * * * * * * * PRESCRIPTION LABELS
A1	82	1401	168.	2011 2022
A2	130	2301	60.	2.19
A3	70	1301	440.	2D70 2H85

FIGURE 4

CLIST - COORDINATE LIST

AAID	X (INCHES)	Y (INCHES)	POLYGON ID	POLYGON AREA (ACRES)	* * * * * * PRESCRIPTION LABELS
73	2.10	4.50	20401	15.	2359
84	2.20	1.67	11302	128.	2.99
87	3.00	4.00	1303	39.	2L29
90	2.50	3.50	5401	92.	2L20 2P49
91	1.10	1.17	3302	23.	1119
92	2.10	3.50	3301	112.	2159

FIGURE 5

DATE: OCT 22, 1981 TIME: 07/37/37 F O R P L O T PRINTER PLOT PART: 1

SAMPLE MAP USED FOR RUN COST ESTIMATES

5000.0 = YSCALE	39.8500 = SWLAT	39.9210 = NELAT	.1000 = XCELL	-1.0 = ACRES	4.00 = XSIZE
5000.0 = XSCALE	105.8700 = SWLONG	105.8000 = NELONG	.1667 = YCELL	3 = NOP	5.17 = YSIZE

```
   0         1         2         3
  *+---------+---------+---------+---------*
 5+                 2859                   +5
  |                                        |
  |                                        |
  |             2>19    25C9               |
  |              2D79                      |
  |                 1119                   |
 4+                          2>332859 2>60 +4
  |                          2>62     2(79 |
  |             2.19         A1            |
  |        2H49          2>20              |
  |                      2>49              |
  |                        2H44            |
 3+          2.19       A2 2H75            +3
  |                                        |
  |                      1119              |
  |         2859 2D312!19                  |
  |              2D52 2>19  2119           |
  |              A3      2=80              |
 2+                      2=99              +2
  |                                        |
  |              2*99  2C89                |
  |           2119  2L29                   |
  |          2D11                          |
  |          2D28                          |
 1+                     1119               +1
  |     2>191119   2G89                    |
  |                                        |
  |    2119                                |
  |         2.19                           |
  |                                        |
 0+                                        +0
  *+---------+---------+---------+---------*
   0         1         2         3
```

FIGURE 6

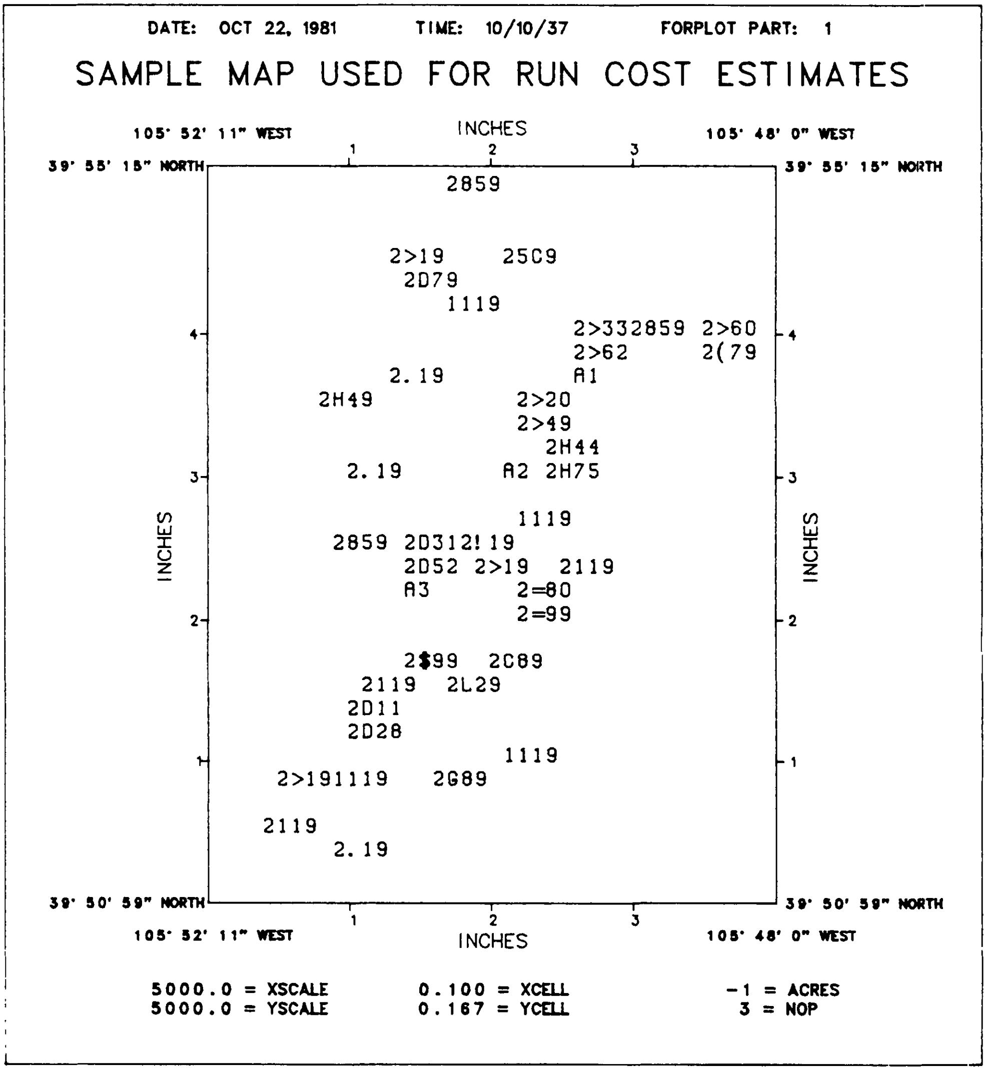
DATE: OCT 22, 1981
TIME: 10/10/37
FORPLOT PART: 1
SAMPLE MAP USED FOR RUN COST ESTIMATES
105° 52' 11" WEST
INCHES
105° 48' 0" WEST
39° 55' 15" NORTH
39° 55' 15" NORTH
2859
2>19 25C9
2D79
1119
2>332859 2>60
2>62 2(79
2.19 A1
2H49 2>20
2>49
2H44
2.19 A2 2H75
1119
2859 2D312!19
2D52 2>19 2119
A3 2=80
2=99
2$99 2C89
2119 2L29
2D11
2D28
1119
2>191119 2G89
2119
2.19
INCHES
INCHES
39° 50' 59" NORTH
39° 50' 59" NORTH
105° 52' 11" WEST
INCHES
105° 48' 0" WEST
5000.0 = XSCALE
5000.0 = YSCALE
0.100 = XCELL
0.167 = YCELL
-1 = ACRES
3 = NOP

FIGURE 7

LOCAL INTERACTIVE DIGITIZING AND EDITING SYSTEM (LIDES)

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ABSTRACT

The Forest Service has identified the need for stand-alone intelligent graphics systems to support a variety of applications to meet the Agency's timber harvesting and land management missions.

Until recently, National Forests and individual units were allowed to acquire their own graphics systems. This has cost the Agency valuable resources, however, due to duplication of effort in the area of applications development. Since many of the applications are of the same type nationally, a real need exists to standardize hard- and software systems in the Forest Service.

The Computer Sciences and Telecommunications Staff Group of the Agency's Washington Office has initiated a Service-wide procurement effort as a first step in standardizing intelligent graphics hardware.

The overall objective of this Local Interactive Digitizing and Editing System (LIDES) development effort is to furnish the Forest Service with a national software capability to interactively digitize, display, and edit graphic data--data which may be represented in the form of points, lines, and polygons with associated feature ID's. The final product of LIDES will be a clean digital file of this graphic data in a common format. The digital file can either be transmitted to a larger computer for use as an input file to another system, or retained for use by local application hardware.

LIDES will be implemented on intelligent graphics systems' hardware which will reside at all levels throughout the Forest Service. Land Management Planning, Timber Management, and Engineering units will be the largest users of LIDES. Operators will range from professional-skilled to semi-skilled personnel.

*This article was written and prepared by U.S. Government employees on official time; it is therefore in the public domain. Mention of commercial products is for convenience only and does not imply endorsement by USDA or its cooperators.

INTRODUCTION

The Forest Service has recognized the importance of digital data bases as sources of speedy and accurate information. Today, there are five nationally supported computer systems in various stages of development and operation that use digital data. They are the TOPôgraphic Analysis System (TOPAS), Digital Terrain Information System (DTIS), Method of Scenic Alternative Impacts by Computer (MOSAIC), Resource Information Display System (RIDS) and Calplotpac.

All these systems have documentation to varying degrees. Most, if not all, are concerned with describing the procedure of how to use the system, and have very little to say about how to collect the digital data they use. The documentation spells out the requirements of the digital data, but dows not help the user in creating the data base that meets these requirements. Also, each system requires a data base of a different format and each requires slightly different identification codes. Therefore, the most time consuming and costly phase of processing any of these programs is the creating of the digital data file. Obviously, this data base must properly represent the information it is suppose to portray, ie. it must be correct. Also is must be acceptable by the computer application program through which the data is intended to be processed, ie., it must be in the proper format. The Local Interactive Digitizing and Editing (LIDES) software development project has been directed at reducing the time consuming process of creating that data base.

The LIDES development effort was begun in August 1980 at the request of our Regional Office in Albuquerque, NM. A work session was conducted with the Regional and Forest personnel to develop a project proposal and feasibility study for LIDES. The Functional and Program Specifications were completed in April 1981. A draft User and Maintenance manual were prepared, as was a Pilot Test Plan for testing LIDES in a user environment. The Pilot Test will take place as soon as the Intelligent Graphic System hardware procurement has been completed and the hardware delivered to Forest Service field units.

DATA COLLECTION AND EDIT

Hardware Components. The Intelligent Graphic System (IGS) will consist of the following mandatory features:

- o Central Processing Unit (CPU)
- o Video Graphics Display (CRT) w/keyboard
- o Plotter
- o Digitizer
- o Printer
- o Magnetic Data Storage
- o Telecommunications Interfaces
- o Display Screen Copy Device
- o Operating System and Utility Software
- o Text Editor

It is intended that the IGS hardware, with the appropriate software, will provide the National Forest and/or Ranger District with the capabilities to support the many graphics applications software packages which have been developed within the Forest Service over the years, ie. Logging System Analysis, Visual Management Planning, Low Standard Road Design, etc., and to perform local interactive digitizing and editing.

Functions to be Performed. The following functions are to be performed with LIDES:

- o Generate a management report of project status information via the CRT screen or printer
- o Initialize the digitizer tablet
- o Digitize graphic data
- o Locate, modify, and/or delete text labels via CRT screen
- o Display graphic data and/or text labels via CRT screen
- o Line plot graphic data
- o Generate data listings via printer or CRT
- o Aggregate and link segments of graphic data into polygons
- o Edit and record text information
- o Link polygon and text information
- o Reformat and transmit digital graphic data

Structure. The flow chart in Figure 1 depicts the structure of the LIDES in a logical flow to collect and prepare digital data for input into a graphics applications system on a remote computer. For local applications, the flow can be interrupted at any stage of data manipulation needed for the particular application. The LIDES software has been designed and coded in a modular format for ease in adapting to changes in systems requirements and hardware configurations within the constraints of the IGS specifications.

REQUIREMENTS

LIDES Requirements. The following requirements were used in developing the LIDES software:

Output. The proposed output product from LIDES will be a clean digital file of the graphic data which was digitized. This file will be produced in the existing Forest Service Modified Data Exchange Format. Several of our national systems (RIDS, DTIS,.. etc.) presently accept this format.

Input. The input document for LIDES can be in the form of maps, other line graphics, photographs, or documents which depict graphic data. Using LIDES, the graphic data can be collected, edited, and stored in a digital file.

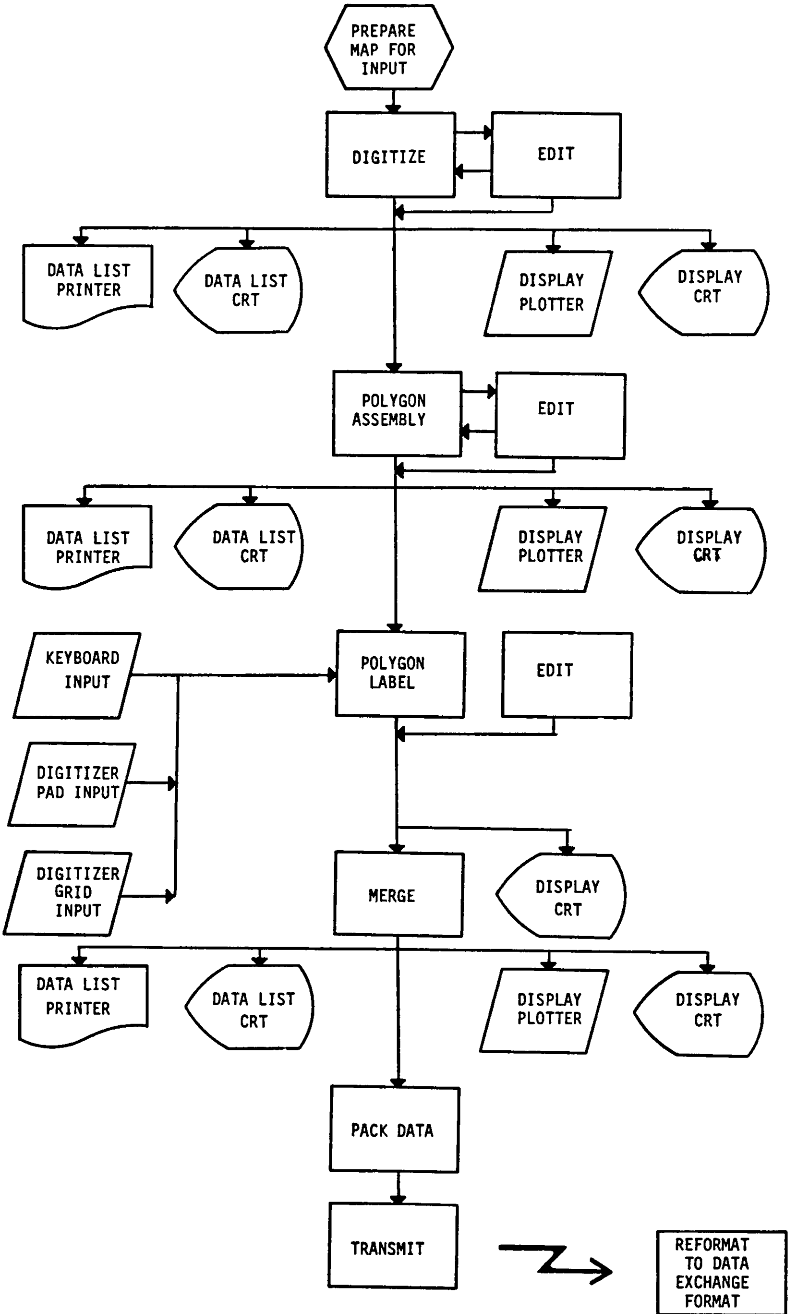
PREPARE MAP FOR INPUT
DIGITIZE
EDIT
DATA LIST PRINTER
DATA LIST CRT
DISPLAY PLOTTER
DISPLAY CRT
POLYGON ASSEMBLY
EDIT
DATA LIST PRINTER
DATA LIST CRT
DISPLAY PLOTTER
DISPLAY CRT
KEYBOARD INPUT
POLYGON LABEL
EDIT
DIGITIZER PAD INPUT
DIGITIZER GRID INPUT
MERGE
DISPLAY CRT
DATA LIST PRINTER
DATA LIST CRT
DISPLAY PLOTTER
DISPLAY CRT
PACK DATA
TRANSMIT
REFORMAT TO DATA EXCHANGE FORMAT

FIGURE 1

Data Sets. The LIDES digital file can either be transferred to a larger computer such as the UNIVAC main frame located at the USDA Fort Collins Computer Center in Fort Collins, CO., for processing with national systems or retained at the local site for use with local applications software. A copy of the digital file may be retained at the local level for ease of updating as required.

Processing and/or data flow. Since the IGS equipment has stand-alone capabilities, all processing and data flow for interactive digitizing and editing will be performed within the system at the local site.

Security, Privacy, and Control. There are no Privacy Act restrictions that apply to this software development. The Forest Service field units will have to establish a routine for making backup tapes if they transmit their LIDES digital file to another site for use in a national or other system.

Information Storage and Retrieval. The IGS hardware will consist of various combinations of hardware components. It is recommended that a ten (10) megabyte magnetic data storage device be a part of the IGS when using LIDES. This will sufficiently support any complex map layer or input document existing or planned within the Forest Service. Either a floppy diskett or magnetic tape may be used to store backup digital files at the local site.

Interfaces with other systems. The clean digital file produced by LIDES may be used as input to other systems. Software will be developed by the Forest Service Engineering Staff to accept the clean LIDES digital file and reformat the data if needed.

Objectives. The LIDES objective is to provide all levels throughout the Forest Service with the software capabilities to perform interactive digitizing and editing on-site and the capability to produce a clean digital file of the input data in a standard format.

EXISTING METHODS AND PROCESSING

The current methods and procedures for digitizing support vary considerably throughout the Forest Service. At present there is little or no digitizing hardware available at the Ranger District or the National Forest. If a Forest needs digitizing support they must send their source documents to the Regional Office or in some cases to another Region for this support. However, digitizing services are also obtained from commercial vendors. It should be noted that the field units are very reluctant to send their source documents outside their unit for digitizing since it may be the only copy and additional effort would be needed to duplicate the sources for digitizing only.

PROPOSED METHODS AND PROCEDURES

The IGS procurement effort is a first step in standardizing the intelligent graphics hardware within the Forest Service. This LIDES development effort will standardize the interactive digitizing and editing software. The hardware and planned software will furnish all levels throughout the Forest Service with stand-alone digitizing and editing capabilities. Field units with IGS hardware can accomplish their digitizing on-site and therefore will retain the use of their source documents within the unit.

Documentation in the form of user manuals are being developed and will be distributed to field users. The maintenance manuals will be furnished by the Washington Office staff responsible for Operations and Maintenance of LIDES.

CONCLUSION

The implementation of LIDES software on the IGS hardware will provide the users with a much needed capability to produce clean digital data files at the local level. These data files can then be utilized with either local applications software or transmitted to a central site such as the USDA computer facility located at Fort Collins, CO. The consequences of not developing a national LIDES package with standard output format, will be an extensive duplication of effort by the field in applications software development to support the digitizing needs required by the field units.

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RELIABILITY CONSIDERATIONS FOR COMPUTER-ASSISTED CARTOGRAPHIC PRODUCTION SYSTEMS

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ABSTRACT

The development of computer-based cartographic production systems is examined from the standpoint of hardware and software reliability factors. The inherent complexity in the design of non-trivial systems is examined and specific techniques from the fields of system engineering and computer science are described. The basis for new hardware systems which incorporate multiple procesors, memories, controllers, mirrored disk files, and fail-soft operating systems is explored. Finally, a system development project team concept is summarized, having the objective of ensuring that more reliable software is built by using structured top-down software engineering techniques.

INTRODUCTION

The field of automated cartography is developing and advancing at a rapid rate. Much of this development in the past has been restricted to systems geared to the research environment, as one would expect during a formative period. The field is currently passing through this phase into one that includes both large and small systems planned for volume production work. Production systems, in general, differ from research tools in several major ways. One of the most important of these is the requirement to meet an established schedule on a regular basis. This paper addresses two of the major factors, hardware and software, whose reliability should be considered in the development of such production systems to insure that the negative impacts of system downtime on production schedules are minimized. The goal is to increase the cartographic community's awareness of the state-of-the-art so that users can improve the reliability of their systems by influencing the designs of in-house and commercially available systems.

COMPLEXITY AND LEVELS OF AUTOMATION

The impacts of unscheduled computer system downtime on operations differ depending upon the kind and degree of automation present in the production sequence. For purpose of analysis, an assumption is made that there exists a threshold value for automation support beyond which production operations would be completely dependent upon a properly functioning hardware/software system to meet established production deadlines. That is, in the event of a major system failure, a retreat to previous manual methods would not be possible since the system would be performing complex operations no longer feasible to perform manually. Suffice it to say that the automated system would exist in order to: (1) meet the production requirement with fewer resources, (2) handle a greater workload, (3) produce higher quality products, or (4) meet more stringent deadlines than the manual system it replaced. Given this assumption, the goal of designing significantly automated production systems revolves around questions relating to the major components of hardware, software, the increased complexity of automation required, a myriad of other ancilliary factors that comprise a functioning system, and the collective impacts of these elements upon the reliability of the total system.

Figure 1 illustrates the growth of system complexity as the level of automation is increased for a system design. After a level of automation is reached that provides significant computer assistance, the complexity begins to grow exponentially.

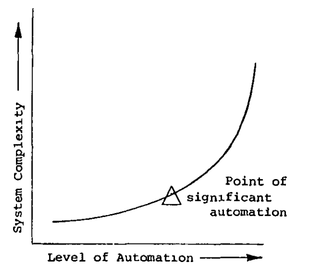


FIGURE 1. Increase in complexity with increase in automation.

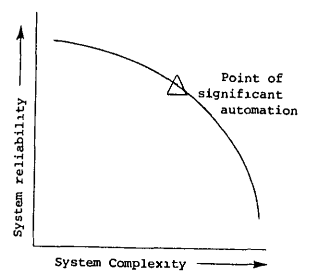


FIGURE 2. Decrease in reliability with increasing complexity.

The dramatic rise in system complexity at the point of exponential growth is due to the fact that the number of required hardware and software system components, and their interfaces, begin to multiply if the system performs any sophisticated functions. As it happens, it is the sophisticated functions in any system that make it really useful and cost effective. It is not surprising, therefore, that when a significantly automated feature is installed in an existing system, a dramatic fall-off in total system reliability is experienced. This effect is shown in Figure 2. It appears that the fundamental problem in implementing and using automated production systems with significantly useful features is one of managing this exponentially growing factor of complexity (Walker, 1978).

SYSTEM AVAILABILITY

The reliability of an item is the probability that it will be able to correctly perform a required function over a stated period of time (Arsenault, 1980). The reliability of a system's hardware and software components can be quite good and the system may operate as planned for extensive periods. However, the additional effects of the time required to bring the system back up when it does fail has to be considered. Production systems must perform to a predictable level on a continuing basis with system failures and repairs taken into account. A measure of the total effects of these factors is the system availability, or the probability that the system will be available to perform the required work at the requested time. This can be defined as:

$$A = \frac{\text{UP TIME}}{\text{UP TIME + DOWN TIME}} = \frac{\text{MTBF}}{\text{MTBF + MTTR}} \qquad (1)$$

where MTBF is the "mean time between failures," and MTTR is the "mean time to repair."

The availability of a system with nonredundant components can be computed as the product of the availability of each of the system components A_i:

$$A(\text{System}) = \prod (A_i) \qquad (2)$$

When the availabilities of all components are identical, then

$$A(\text{System}) = (A_i)^n \qquad (3)$$

The important point summarized here is that the total system availability will be less than the availabilities of the individual components, as shown in Figure 3. The problem then, is to find ways of increasing the system availability for hardware and software components in the face of increasingly complex designs.

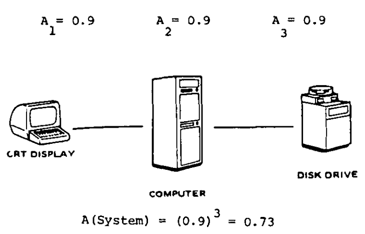


Figure 3. System Availability Less Than That Of Components

A SYSTEMS ENGINEERING APPROACH

Having established the need to take levels of automation, complexity, reliability, and system availability into account in the development of cartographic systems, the next step is to identify existing techniques that have already proven effective elsewhere. The field of systems engineering has a well developed body of knowledge and specific techniques for developing systems throughout a life cycle process (Hall, 1962). All of these techniques are ultimately directed to the specification of hardware, software, facilities, personnel skills, training, and procedures needed to meet customer requirements within predetermined reliability criteria.

One postulate of this paper is the view that these existing techniques should be transferred and applied to the development of cartographic systems in a formal way, instead of reinventing the wheel on a trial-and-error basis. Some of the particular kinds of systems engineering techniques that could contribute to more reliable cartographic systems include those of precise system specification, technical reviews, configuration management, maintainability and reliability, quality assurance, human factors engineering, software engineering, software verification and validation, and production management. The remainder of this paper will focus upon the techniques for systematically increasing a cartographic system's hardware and software availability in the face of increasing design complexity for significant levels of automation.

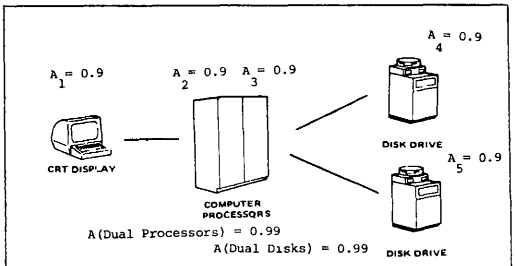
HARDWARE TECHNIQUES

Until around 1975, the generally accepted method of increasing the availability of a computer was to provide a duplicate system (Champine, 1978). This "stand-by" technique was common, especially for batch processing systems, in which punched cards were the primary method of data entry and/or user interface. This method was expensive and cumbersome and not very effective. It required the maintenance of duplicate data bases, duplicate software libraries, and, in some cases, additional staffing. In addition, where the back-up and primary computers differed (such as different manufacturers or different operating systems) the staff was required to be intimately familiar with more than one system. This resulted in a duplication of effort and decreased overall productivity. At about the same time, the methods of using the computer had also begun to change.

During this period applications evolved from the batch (punched card) oriented mode to an on-line environment. System users began to interact directly with hardware and software through terminals rather than key punch machines. Some users began to use timesharing on large mainframe computers, while others acquired dedicated minicomputers and integrated them into their system designs. Powerful microcomputers are now available to perform most if not all of the functions for which minicomputers were recently used at a fraction of the cost. Similarly, the supermini's of today are displacing mainframes for many applications.

These changes have had a major impact upon the way users have come to view their work. System failure in a batch operation has little impact on its users if it can be corrected in a few hours; but system failure in an interactive or real-time environment has a catastrophic impact and system failures once taken in stride are now considered intolerable. The upshot of this evolution to on-line operations using mini and microcomputers is to place far greater demands upon system design regarding reliability and the need to exploit the use of new technology to increase overall system availability.

The primary method used to increase system availability through hardware design is by the use of redundant hardware components (Katzman, 1977). Figure 4 shows the effect of using redundant processors and disk subsystems to achieve a system availability greater than those of the individual parallel components and the system availability of Figure 3.



$A(System) = (0.9)(1.0 - (1.0 - 0.9)^2)(1.0 - (1.0 - 0.9)^2) = 0.88$

Figure 4. Parallel Redundancy Increases Availability

This effect is due to the definition of availability for redundant parallel elements:

$$A(System) = 1 - \prod (1 - A_i) \qquad (4)$$

When the availabilities of all elements are identical, then

$$A(System) = 1 - (1 - A)^n \qquad (5)$$

This discussion of hardware redundancy is, of course, not new (Arsenault, 1980). The purpose is to highlight the basis for techniques currently being employed by a number of computer hardware manufacturers to build commercially available "fail-safe" systems. By trading off the competing factors of reliability, complexity, performance, maintenance, and cost, designers are able to produce systems with extremely high system availability values (Katzman, 1977). The point to seriously consider, both by in-house system implementors as well as vendors of cartographic systems, is that effective hardware redundancy techniques are available for use in production system designs.

NEW TECHNOLOGY

Special-purpose, one-of-a-kind, and extremely expensive hardware/software systems incorporating ultra high reliability features have been in use for several years in military and space applications. Much of this technology is becoming available to designers of commercial and scientific systems as low cost off-the-shelf items. The hardware includes the use of redundant minicomputers, microprocessors, and integrated operating systems support for automatic reconfiguration of system components in the event of component failure. A major benefit of the architecture of these computing systems is the automatic data file recovery features which protect the integrity of the data base as components fail (Bartlett, 1978).

One manufacturer that has led the field in this area is the Tandem Company of Cupertino, California (Bartlett, 1978). Tandem has had systems in the field for about seven years now and has proven technology. The success of this company appears to have started a trend with several new companies specializing in this type of system. Stratus, Inc. of Natick, Massachusetts, and, August Systems, of Salem, Oregon have announced similar fault-tolerant products (Boggs, 1981). Even the more established firms are beginning to orient their products to fault-tolerant designs. IBM has announced the development of fail-safe features for its processors with similar redundancy characteristics to the Tandem. Briefly, these manufactures use a combination of redundant hardware, with integrated software support, to eliminate system failure due to the failure of any single major component, such as the central processor, central memory, peripheral controllers, and disk drives. Unlike stand-by mode designs, these systems fully utilize all resources, such as the integrated modular processors and shared memory. Therefore, the effective system capacity is increased and available for primary operations. The replacement of failed components can even be performed with the system running. Data base integrity is protected during disk or controller failure by "mirroring," or automatically updating copies of, files. Access latency for data retrievals is reduced by the system use of the mirrored files for data base operations.

It appears that the trend toward commercially available fault-tolerant systems is a major development in the computer industry. It is not too early for designers of digital cartographic systems to make their needs known and incorporate this class of hardware into production system designs.

SOFTWARE TECHNIQUES

One of the major pitfalls inherent in the planning and implementation of computer-based systems is the tendency to overlook or underestimate the software problem. Hardware is tangible and can be seen, touched, moved about and is associated with clear and complete specificiations. If a hardware component malfunctions, it is a relatively straightforward process to trace the problem, isolate the malfunctioning elements, and repair the equipment. As demonstrated above, there exist concrete analytical techniques for predicting the reliability of hardware elements that can be applied to the design process.

Unfortunately, this is not the case for software which is almost never associated with clean and complete specifications. In many ways a system description is the tip of the iceberg, with hardware components being clearly visable and the much larger and more elusive software elements concealed beneath the surface. The issue of software correctness and reliability has emerged as a serious problem only within the last decade. Efforts have been made to develop analytical techniques for application to software reliability without much practical success; and unlike hardware, the use of redundancy is not an effective way to improve software reliability. The two main approaches that have been pursued relate to either formal proofs of program correctness, in the sense of mathematical theorem proving using artificial intelligence techniques, or quality assurance, through the use of rigorous and systematic software verification and validation procedures.

SOFTWARE ENGINEERING

The techniques that are emerging as being of practical importance in attacking the software problem have evolved from the systematic testing approach, but relate to even more fundamental issues than testing alone. It has been estimated that only about one-half of all software errors are due to programming mistakes (Champine, 1978). The remaining errors are due to inadequate specification of the system requirements and noise introduced in technical communications between the individuals performing the steps in the software development process. The entire range of software development activity is revamped and made more precise and systematic under the discipline of software engineering (Mills, 1980). This relatively new approach emphasizes specific structured techniques for controlling the technical communications process and the complexity inherent throughout the software development steps of analysis, specification, design, coding, testing, implementation, and documentation. The buzz words for these tools are composite (modular) design and top-down structured programming. This approach is proving effective because the approach to containing the fundamental software problem consists of the management and control of exponentially increasing complexity.

SOFTWARE DEVELOPMENT METHODOLOGY AND RELIABILITY

The software engineering approach contrasts sharply with the historical method where most software is generated when an enthusiastic programmer or other technical individual quickly dashes off a few lines of code in a flash of inspiration and then expands it into a complete program as more ideas appear. This kind of effort results in a patchwork of code which performs many functions using an unnecessarily complex logic flow. It is nearly impossible to debug the program completely and only the author is able to understand it. For this reason it is very difficult to maintain through normal software changes and the unreliability grows with each modification. The decision is made through default to try to eliminate the ensuing software bugs with a long and difficult period of testing, rather than using a brief but valuable initial period to systematically "design out" most errors before coding is started. Under these circumstances, it is impossible to test for all the errors generated. Even when development is carefully controlled, there is an early point of diminishing return where it is a waste of time to continue further testing due to the large number of parameters involved, the inherent complexity of the code, and the difficulty to simulate the "live data" conditions of an operational environment. For this reason, it has been said that, like wine, software improves with age (Champine, 1978).

BEYOND SOFTWARE ENGINEERING

Even the use of structured software engineering techniques, such as top-down design, stepwise refinement, and structured programming, appear to suffer from certain shortcomings. Claims for their effectiveness in increasing software quality and reliability are sometimes inconsistent among different organizations. It has been suggested that these techniques are good, but are not sufficient and that the organizational structure of the project has at least as great an impact upon the quality of software generated as does the programming techniques employed (Walker, 1978).

This factor of organizational structure for software development (the team approach) has been found to be the single most important new method of reducing the remaining 50% of software errors not due to coding mistakes. The team structure approach is a direct attack on the increasing complexity problem by formalizing precise communication between the major tasks of transforming objectives into system requirements, requirements into a design, and the design into accurate software code. Each successive transformation decomposes subsequent development activities into deeper levels of detail revealing increased complexity. The team organizational structure, if properly established, increases the effectiveness of the necessarily detailed technical communication between team members and reduces the information loss and introduction of extraneous noise due to the transformation process. The number of detailed relationships requiring accurate transformation, and the level of detail in the communications required, grows in proportion to increasing system complexity (Walker, 1978).

Since most efforts are too large for one individual to accomplish, the team organizational structure becomes an operating model of the software development process and is a major tool for controlling communications among members and ensuring a disciplined approach to software development. Even if nothing else is achieved, however, a properly structured team organization will ensure that (1) needed communication will occur, (2) some degree of design activity and problem solution will be used before software coding begins, and (3) basic documentation will be produced. Figure 5 depicts a software development team structure that has been proposed for use in the Office of Aeronautical Charting and Cartography, National Ocean Survey for all system development efforts.

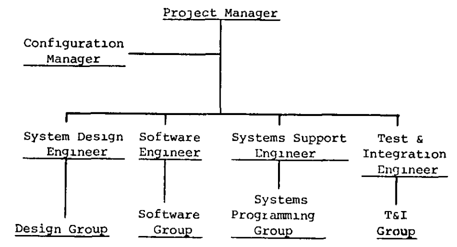


Figure 5. Software Development Team Structure

THE SOFTWARE DEVELOPMENT TEAM

The structure depicted in Figure 5 is a variation on the chief programmer team concept introduced by Mills and modified by Tausworthe (Tausworthe, 1979).

The project manager functions as the lead technical authority, or "chief programmer," in addition to required project management duties. Not shown on the chart is a higher level manager who performs most of the traditional project management functions concurrently for several of these projects.

The configuration manager assists the project manager to insure that all activities are performed under the disciplined software engineering approach outlined in the official standards and procedures handbook. This handbook is an integral component of the project team concept and serves as a basic standards reference for all team members and all projects. The configuration manager also performs the traditional configuration control function for the team.

The system design engineer assists the project manager in all phases of the requirements definition, analysis, and system design activities. The system design is produced using top-down structured techniques and design walkthroughs. Specific deliverables are produced out of these tasks and are placed under immediate configuration control after acceptance by management.

The software engineer is responsible for designing and implementing the software modules using structured programming techniques. As modules are added to the program library, they are placed under configuration control. Subsequent changes to these modules can then only be made through the configuration management process which requires project manager approval.

The test and integration engineer is responsible for the development and execution of a comprehensive system test plan in parallel with the design and programming efforts. As modules become available for testing, they are exercised against the plan and deficiencies noted. The test engineer does not debug the module, but returns it to the software development library under configuration control so that the programming group can correct the identified deficiencies.

The systems support engineer performs the typical systems programming function and insures that the operating system, data base management system, compilers, graphics packages, etc. are properly installed and operating. Assistance is provided to other team members for problems experienced with the system hardware and vendor-supplied software.

CONCLUSION

Rapid advances are being made in the area of systems reliability that designers of cartographic systems should exploit. These developments are occuring in two primary areas: (1) new ultra-reliable hardware systems incorporating built-in component redundancy using microprocessors and minicomputers, and (2) advances in the way reliable software can be developed using top-down structured techniques and software development team concepts. The field of cartographic automation has reached the point of development that requires the serious consideration of these new techniques. Without the use of these or similar methods, the design and development of truely effective cartographic production systems could be significantly retarded.

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SITE-SPECIFIC ACCURACY OF DIGITIZED PROPERTY MAPS

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BIOGRAPHICAL SKETCH

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ABSTRACT

The Westport Land Records Project, at the University of Wisconsin, is a multidisciplinary research project devoted to the improvement of land information. One of the goals of the project is to investigate the feasibility of merging various source map data by fitting digital representations of maps to ground surveyed control points. One set of source maps used in the study are the 1 inch = 400 ft. (1:4800) sectionalized property maps of Dane County, Wisconsin, which are currently being used for tax assessing, zoning, planning, permit granting, and floodplain insurance purposes. These maps were originally produced in the 1930's and updated from time to time. They are known to contain gross errors. Some of these maps have been digitized and adjusted to surveyed ground points. A series of three two-dimensional transformation models have been investigated: 1) conformal Helmert, 2) affine, and 3) projective. In order to assess the appropriateness of these models and the site-specific accuracy of the computed coordinates, adjusted map positions have been compared to those of field monumented points whose positions were determined by ground survey but withheld from the adjustment.

INTRODUCTION

The Westport Land Records Project, at the University of Wisconsin-Madison, is a multidisciplinary research effort in which the University's Department of Landscape Architecture, Department of Civil and Environmental Engineering and School of Natural Resources, the U.S. Department of Agriculture, the Dane County Regional Planning Commission, and the Wisconsin State Cartographer's Office are participating (Moyer, et al., 1981). One of the activities of the project is the investigation of the integration of resource, planimetric, and property maps by adjusting digitized map coordinates to surveyed ground control (Mills, 1982). The base maps for this investigation are the Dane County sectionalized property maps at a scale of 1:4800. These maps are currently used by the county for tax assessing, zoning, planning, permit granting, and floodplain insurance purposes. The maps, on linen, were originally produced, in the 1930's, from record survey information and legal descriptions. They are known to contain gross errors mainly attributable to a lack of spatial data on property boundaries and to drafting. They are manually updated from time to time as survey information becomes available.

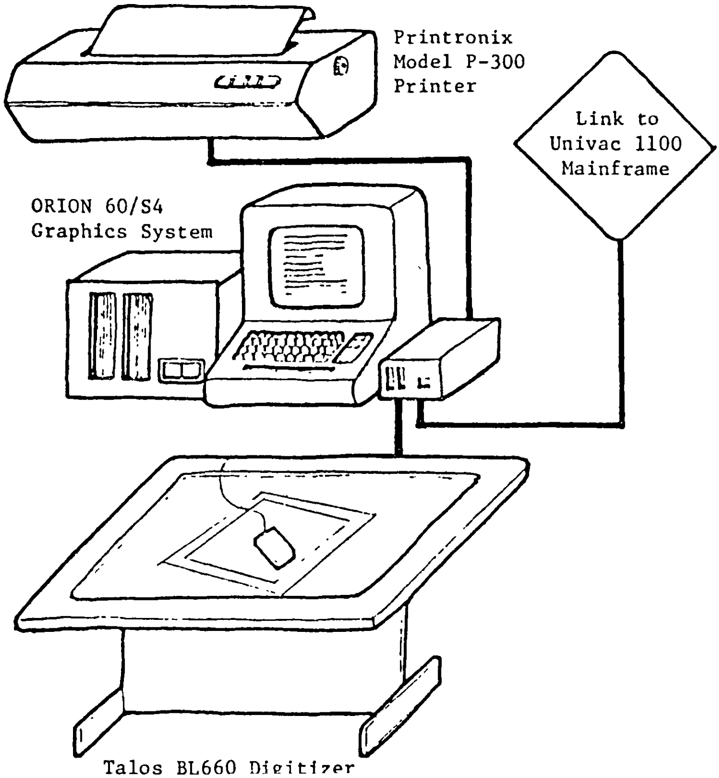
All of the section and quarter section corners in Westport Township, Dane County, have been remonumented in recent years under a county program. State plane coordinates (Wisconsin South Zone) on a number of these corners have been determined by ground survey. These coordinates are used, on the Westport Project, to control the transformation of map coordinates, obtained by digitizing the property maps, into the state plane system. Three different transformation models, with varying amounts of control, have been used.

Prior to the work reported herein, questions arose as to the appropriateness of the selected mathematical transformation models and as to the accuracy of the final transformed coordinates on property corners. The Northeast Quarter of Section 21, Township 8 North, Range 9 East of the 4th Principal Meridian was selected as a test site. The intent was to establish state plane coordinates on a number of property corners by ground survey and to compare these coordinates to those obtained by digitizing the property maps. This site was selected because it contains four residential subdivisions laid out within the past seventeen years. It was anticipated that a number of original property corner monuments would be recoverable in the proximity of existing horizontal control. Also, state plane coordinates of ten property corners along the east line of the Northeast Quarter of Section 21 had already been established in a prior study (Crossfield and Mezera, 1981).

DATA ACQUISITION

Map Digitization

Paper reproductions of the original linen property maps were digitized on a Talos BL660 Digitizer. The Digitizer has a bombsight cursor and a resolution of 0.03 mm. The standard deviation in a single observation on the digitizer was determined to be $\pm$ 0.18 mm from repeated measurements. At a scale of 1:4800, this results in a ground positional error of $\pm$ 0.85 meters. Figure 1 (taken from Mills (1982)) illustrates the full configuration of the equipment used for data capture. The ORION 60/54 Graphics System serves as a display and storage device for digited coordinates. Data may be dumped directly to the printer or transmitted to the university's UNIVAC 1100 mainframe computer which is used for hard-copy graphics.



Hardware Configuration for Map Digitization

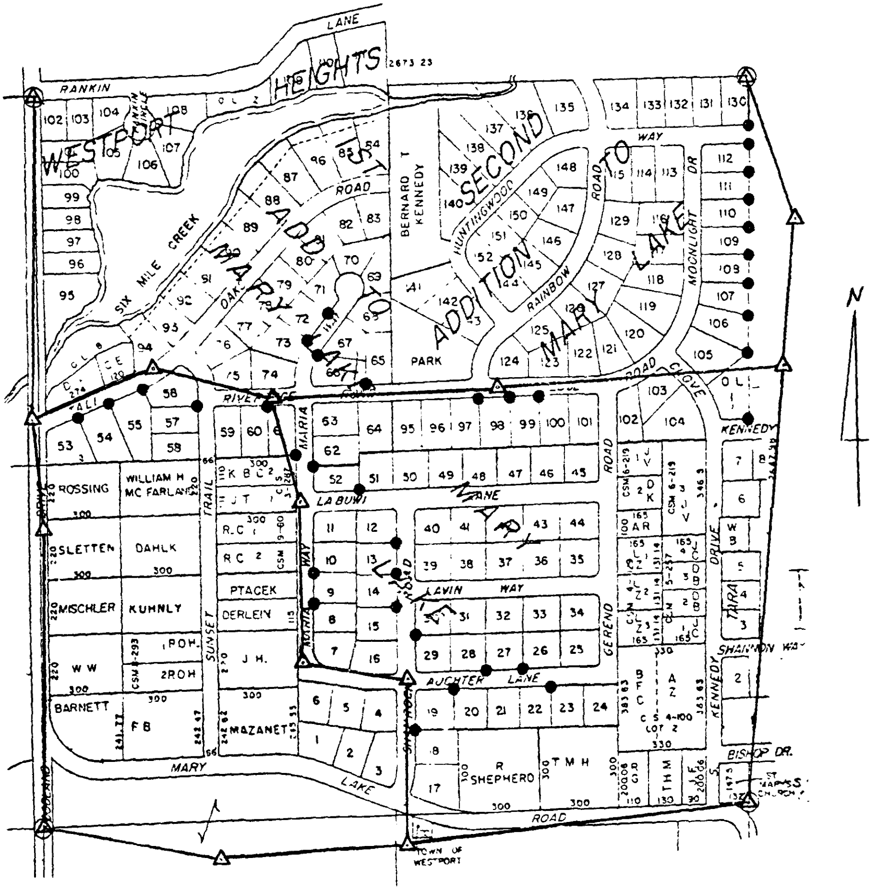
Figure 1.

The digitized map coordinates are subject to three sources of error: 1) errors in the original property maps, 2) errors in the reproduction process, and 3) errors in the digitizer measurements.

Ground Survey

The ground survey entailed two days of point recovery and two days of measurement. Successive property corners were recovered at random locations in three of the subdivisions. Only solid, undisturbed pins were used. Thirty-six pins were eventually unearthed and surveyed. Traverse was run connecting the recovered property corners to all four of the corners of the Northeast Quarter of Section 21. State plane coordinates of these quarter section corners were known. Figure 2 illustrates the configuration of the traverse network and the property corners.

The actual measurements were done with a Zeiss Elta 2S total station surveying instrument which facilitated electronic angle, distance, and elevation difference measurement plus automatic reduction and recording of surveyed data. Based



Traverse Network and Surveyed Property Corners

Figure 2.

strictly on surveying experience, this instrument resulted in somewhere between a 30-50% savings in measuring time. Also, the instrument allowed the entire survey to be performed with a two-man crew. The Elta is equipped with several additional computing capabilities such as free stationing and coordinate recall and computation. Were we to return to Westport, it would be possible to recall traverse point coordinates and coordinates for other points to be found resulting in the machine computing and measuring to search areas.

DATA REDUCTION

Map Digitization

The digitized map coordinates of the property corners were run through a series of three transformations. The first transformation is a four-parameter, conformal, Helmert of the form

$$N_T = N_{CG} + \lambda D^* \cos(Az+\phi)$$
$$E_T = E_{CG} + \lambda D^* \sin(Az+\phi) \qquad (1)$$

where

N_T, E_T are the transformed coordinates,

N_{CG}, E_{CG} are the coordinates of the center of gravity of the control points in the state plane system,

λ is a scale factor,

ϕ is a rotation angle,

$$D = \sqrt{(n-n_{CG})^2 + (e-e_{CG})^2}$$

$$Az = \tan^{-1}\left(\frac{e-e_{CG}}{n-n_{CG}}\right),$$

n,e are map coordinates to be transformed,

n_{CG}, e_{CG} are map coordinates of the center of gravity of the control points.

The second transformation is a six-parameter affine of the form

$$N_T = a_1 n + a_2 e + a_3$$
$$E_T = b_1 n + b_2 e + b_3, \qquad (2)$$

where

$a_1, a_2, a_3, b_1, b_2, b_3$ are the affine coefficients,

N_T, E_T, n, e are as before.

The third transformation is an eight-parameter projective of the form

$$N_T = \frac{a_1 n + a_2 e + a_3}{c_1 n + c_2 e + 1}$$

$$E_T = \frac{b_1 n + b_2 e + b_3}{c_1 n + c_2 e + 1} \qquad (3)$$

where

$a_1, a_2, a_3, b_1, b_2, b_3$ are the projective coefficients,

N_T, E_T, n, e are as before.

The three transformations require a minimum of two, three, and four control points, respecitvely, in order to solve for their unknowns. Any redundancy results in a least squares fitting of the model to the control. After a least squares fit, transformed coordinates may be refined by distributing the residuals at the control points using an inverse weighted distance function of the form

$$\Delta N_j = \frac{\sum_{i=1}^{n} v_{N_i} * P_i}{\sum_{i=1}^{n} P_i} \qquad \Delta E_j = \frac{\sum_{i=1}^{n} v_{E_i} * P_i}{\sum_{i=1}^{n} P_i}$$

where

$\Delta N, \Delta E$ are to be added to the transformed coordinates of point j,

V_{N_i}, V_{E_i} are the residuals in the transformed coordinates at the ith control point,

$P_i = \frac{1}{S_i}$ for $S_i > 1$,

$P_i = 1$ for $S_i \leq 1$,

$S_i = \sqrt{(N_j - N_i)^2 + (E_j - E_i)^2}$,

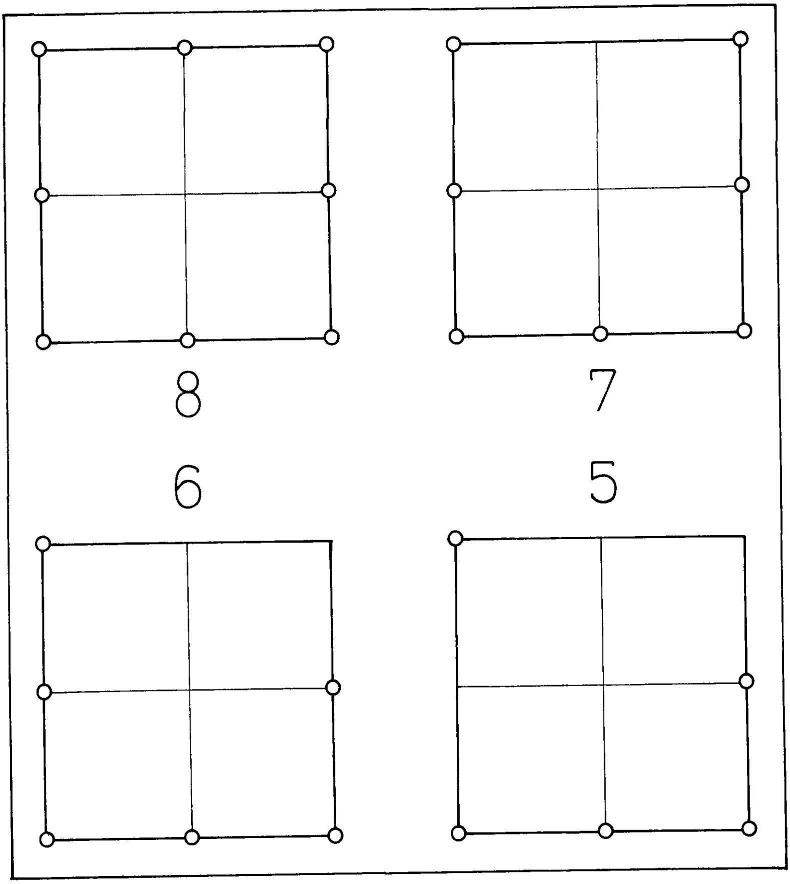
N_j, E_j are the transformed coordinates of point j,

N_i, E_i are the transformed coordinates of the ith control point.

Each of the transformations were performed for the four different configurations of control in Figure 3. Initially all eight section and quarter section corners were used as control in the transformations. The successive configurations of seven, six, and five control points were determined by discarding the control point with the largest residual in the conformal Helmert transformation of the immediately previous configuration.

Ground Survey

The measured traverse data was adjusted by the method of least squares. The network had nine degrees of freedom. The largest semi-major standard error ellipse axis was 15 mm and the largest semi-minor standard error ellipse axis was 11 mm. Result of the χ^2 test on the variance of unit weight at 95% confidence were as follows:



Control Configuration for Map Transformations

Figure 3.

H_o: $\sigma^2 = \sigma_o^2$ vs. H_1: $\sigma^2 \neq \sigma_o^2$

$$\frac{df\ \hat{\sigma}_o^2}{\chi^2_{1-\frac{\alpha}{2},df}} < \sigma_o^2 < \frac{df\hat{\sigma}_o^2}{\chi^2_{\frac{\alpha}{2},df}}$$

where

σ^2 = variance of unit weight,

σ_o^2 = a priori estimate of σ^2 = 1,

$\hat{\sigma}_o^2$ = a posteriori estimate of σ^2 = 1.46,

df = degrees of freedom = 9,

$\alpha = 5\%$,

$\chi^2_{.025,9} = 2.70$,

$\chi^2_{.975,9} = 19.02$,

and $1.0 \leq 1.0 \leq 7.1$ (accept H_o).

The coordinates of the property corners were computed as sideshots from the adjusted traverse coordinates.

ACCURACY ANALYSIS

The approach used in analyzing the accuracy of the transformed property maps is that proposed by the Specifications and Standards Committee of ASP as presented in Merchant (1982). The Circular Map Accuracy Standard at the scale of the source maps (1 inch = 400 ft., 1:4800) requires that 90% of the well-defined points be in error by less than

2.6 m (8.6 ft.) for Class 1 maps,
5.2 m (17. ft.) for Class 2 maps,
7.8 m (26. ft.) for Class 3 maps.

These correspond to standard errors (1σ) of

1.2 m for Class 1 maps,
2.4 m for Class 2 maps,
3.6 m for Class 3 maps.

Compliance with these standards is examined by testing for bias (student's t) and precision (χ^2) in both the northing (Y) and easting (X) directions of the maps at a 95% confidence level. Any given map passes the test if

$$|t_N| \leq t_{n-1,\alpha} \quad , \quad |t_E| \leq t_{n-1,\alpha} \quad ,$$

$$|\chi^2_N| \leq \chi^2_{n-1,\alpha} \quad , \quad \text{and } |\chi^2_E| \leq \chi^2_{n-1,\alpha}$$

where

$$t_N = \frac{1}{S_N}(\overline{\Delta N})\sqrt{n} \quad , \quad t_E = \frac{1}{S_E}(\overline{\Delta E})\sqrt{n} \quad ,$$

$$\chi^2_N = \left(\frac{n-1}{\sigma^2}\right) S^2_N \quad , \quad \chi^2_E = \left(\frac{n-1}{\sigma^2}\right) S^2_E \quad , \qquad (5)$$

$\overline{\Delta N}, \overline{\Delta E}$ are the sample means of the discrepancies ($\Delta N, \Delta E$) in the northings and eastings at the check points,

S_N, S_E are the corresponding sample standard deviations,

n = number of check points,

σ is the standard error as stated above for Class 1, 2, and 3 maps.

Table 1.
Coordinate Discrepancies for Conformal Helmert Transformation Using 8 Control Points

Point #	Undistributed Residuals ΔN(meters)	Undistributed Residuals ΔE(meters)	Distributed Residuals ΔN(meters)	Distributed Residuals ΔE(meters)
1	-5.08	-0.30	-3.19	-0.31
2	-5.20	-0.28	-3.30	-0.27
3	-5.23	1.13	-3.31	1.19
4	-5.08	-0.52	-3.09	-0.35
5	-4.28	-0.74	-1.99	-0.33
6	0.39	-2.76	2.79	-2.22
7	-0.83	2.79	1.71	3.26
8	-1.18	2.40	1.41	2.89
9	-4.41	1.48	-1.96	1.90
10	-4.16	1.91	-1.94	2.19
11	-1.66	-3.25	0.96	-2.57
12	-1.10	-3.93	1.42	-3.22
13	-0.33	-2.02	2.05	-1.28
14	-2.25	-1.27	-0.25	-1.02
15	-1.68	-1.27	0.26	-1.05
16	-3.81	2.30	-2.12	2.30
17	-1.60	0.50	-0.21	0.40
18	-0.30	0.80	0.98	0.63
19	-1.65	4.89	-0.25	4.57
20	-0.68	4.77	0.81	4.54
21	-3.40	1.35	-2.17	0.81
22	-1.10	6.55	0.07	5.66
23	-1.11	5.57	0.09	4.54
24	-1.03	2.84	0.16	1.62
25	-1.08	2.99	0.08	1.90
26	-1.75	2.12	-0.63	1.30
27	-3.87	4.59	-2.88	3.81
28	-4.51	-2.02	-1.27	-0.35
29	-8.28	-2.20	-5.21	-0.74
30	-4.04	-1.96	-1.20	-0.76
31	-4.88	-1.44	-2.21	-0.45
32	-4.20	-1.39	-1.70	-0.60
33	-3.84	-1.22	-1.48	-0.61
34	-3.62	-1.08	-1.39	-0.64
35	-4.37	-0.10	-2.41	-0.06
36	-5.02	0.32	-3.26	0.03

Also,

$$t_{35,.05} = 1.690 \quad \text{and} \quad \chi^2_{35,.05} = 49.76. \tag{6}$$

As indicated by equations (5), all three classes of map must pass the same test for bias. However, because of the appearance of the standard error in the sample χ^2_N and χ^2_E statistics, precision requirements are not as stringent for map classes of lower accuracy as they are for map classes of higher accuracy.

Table 1 contains the coordinate discrepancies at the thirty-six check points for the conformal Helmert transformation using eight control points. The first two columns are data derived prior to refinement by residual distribution. Since the transformation contains only two translations, one rotation, and one scale factor, these discrepancies are indicative of the error in the digitized map at ground scale. The second two columns are data derived after the distribution of residuals using equations (4). There is a downward trend in the magnitude of the residuals after the coordinate refinement.

Table 2 contains the sample means and standard deviations in the coordinate discrepancies at all check points for each of the control configurations, versus each of the transformations with distributed residuals and without. The magnitude of the mean residuals tends to increase as the number of control points decreases. However, there is no corresponding trend in the standard deviations.

The affine transformation should account for some of the systematic effects of paper stretching during map reproduction. In fourteen out of sixteen cases the mean residuals for the affine transformation are smaller than those for the conformal. The projective transformation should account for differential scale factors and for misplotting of the section and quarter section corners. In thirteen out of sixteen cases the mean residuals for the affine transformation are smaller than those for the conformal. In nearly all cases the affine and projective transformation have smaller standard deviations than the conformal.

Table 3 contains absolute values of the sample t statistics and the results of the tests when they are compared to the theoretical t statistic in equations (6). The number of failures of the test for bias increases as the number of control points decreases. When eight control points are used, the affine and projective transformations, in all cases, have less bias than the conformal. However, there is no clear choice to be made between the affine transformation and the projective. As can be seen, coordinate refinement, by distribution of the residuals, can actually introduce additional bias in the map. None of the maps can be considered bias-free because, in all cases, the t test failed in one or both of the N and E directions.

From equations (5) and (6) and the given acceptable standard errors for the three map classes, the maximum allowable sample standard deviations in either direction are:

$$s_{max} = \frac{(\chi^2_{n-1,\alpha})\sigma^2}{n-1} = \frac{49.76*1.2^2}{35} = 1.43 \text{ m (Class 1)},$$

$$s_{max} = \frac{49.76*2.4^2}{35} = 2.86 \text{ m (Class 2)},$$

$$s_{max} = \frac{49.76*3.6^2}{35} = 4.29 \text{ m (Class 3)}.$$

Table 2.
Sample Means and Standard Deviations in Coordinate Discrepancies
(Units are Meters)

Number of Control Points		Conformal				Affine				Projective			
		Undistributed Residuals		Distributed Residuals		Undistributed Residuals		Distributed Residuals		Undistributed Residuals		Distributed Residuals	
		ΔN	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN	ΔE
8	Mean	-2.95	0.59	-0.96	0.74	0.45	0.35	0.56	0.57	-0.12	0.73	0.03	0.71
	Std.Dev.	1.96	2.62	1.84	2.14	1.45	2.30	1.68	2.06	1.51	2.04	1.79	1.99
7	Mean	-5.04	-0.40	-3.17	0.11	-1.69	0.78	-1.58	1.06	-2.05	1.06	-1.94	0.79
	Std.Dev.	2.06	2.67	1.55	2.10	1.50	2.25	1.47	2.04	1.45	2.08	1.45	3.00
6	Mean	-7.76	-2.03	-6.59	-1.94	-2.31	-0.91	-2.24	-0.72	-2.36	-0.20	-2.23	-0.09
	Std.Dev.	2.34	2.73	2.38	2.69	1.56	2.49	1.55	2.52	1.63	2.45	1.62	2.46
5	Mean	-6.63	-2.54	-5.37	-2.46	-2.20	-1.27	-2.09	-1.12	-2.71	-0.92	-2.53	-0.79
	Std.Dev.	2.20	2.66	2.26	2.62	1.59	2.42	1.59	2.43	1.77	2.56	1.77	2.57

Table 3.
Results of the Tests for Bias in Northing and Easting

Number of Control Points	Conformal				Affine				Projective			
	Undistributed Residuals		Distributed Residuals		Undistributed Residuals		Distributed Residuals		Undistributed Residuals		Distributed Residuals	
	$\|t_N\|$	$\|t_E\|$	$\|t_N\|$	$\|t_E\|$	$\|t_N\|$	$\|t_E\|$	$\|t_N\|$	$\|t_E\|$	$\|t_N\|$	$\|t_E\|$	$\|t_N\|$	$\|t_E\|$
8	9.03 Fail	1.35 Pass	3.13 Fail	2.07 Fail	1.86 Fail	0.91 Pass	2.00 Fail	1.66 Pass	0.48 Pass	2.15 Fail	0.10 Pass	2.14 Fail
7	14.7 Fail	0.90 Pass	12.3 Fail	0.31 Pass	6.76 Fail	2.08 Fail	6.45 Fail	3.12 Fail	8.48 Fail	3.06 Fail	8.03 Fail	1.58 Pass
6	19.9 Fail	4.46 Fail	16.6 Fail	4.33 Fail	8.88 Fail	2.19 Fail	8.67 Fail	1.71 Fail	8.69 Fail	0.49 Pass	8.26 Fail	0.22 Pass
5	18.1 Fail	5.73 Fail	14.3 Fail	5.63 Fail	8.30 Fail	3.15 Fail	7.89 Fail	2.77 Fail	9.19 Fail	2.16 Fail	8.58 Fail	1.84 Fail

Using these criteria, and the values in Table 2, all of the maps except one pass the Class 2 precision test. The remaining map passes the Class 3 precision test.

CONCLUSIONS

It was our original intent to perform what we believed was one of the only studies of the relationship between actual property corners with legal significance and their representation on maps which have undergone mathematical manipulation. We had hoped to thereby ascertain the usefulness of our digital map product.

As can be seen from the tabulated results, none of our digital map products satisfies the large scale map accuracy standards as proposed by ASP. Most passed the test for Class 2 precision, but all failed the test for bias. We did note an improvement in the computed positions due to the mathematical transformation.

More importantly however, this study had made obvious the intuitive idea that no amount of mathematical manipulation of an inherently poor source document can result in an accurate final product. However, we do not feel that our effort has been entirely fruitless. The digital map products are certainly more versatile than their linen counterparts, and may be useful for planning and zoning purposes.

The further implication that existing land records cannot be used to produce accurate property maps is not substantiated by this work. Further investigation is required.

ACKNOWLEDGEMENT

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AN AUTOMATED MAP PRODUCTION SYSTEM FOR THE ITALIAN STATE OWNED TELEPHONE COMPANY

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ABSTRACT

The Italian state-owned telephone company-SIP- decided one year ago to start a project to automatize the production of its cartographic documentation, including networks, schematic maps and inventories.

The scope of the project was to automatize the production of their maps and to create a data base for easy up-dating. At the present time, SIP has to deal with a very large amount of drawings, which need continuos updating.

Labour and costs for updating maps is constantly increasing thus SIP has decided to test the Kongsberg System. They have evaluated time savings and total benefits and hence purchased a complete system for Rome, including one automatic digitizer and an interactive graphic system. The result of the project after a test period of six months is that the ratio between manual and traditional method of map production and the computer assisted method is 5:1.

In addition to that, SIP has at its disposal an easy and flexible data base for updating their work.

It is interesting to point out that SIP was the first European telephone Company to start production of a computer assisted process for its utility maps.

INTRODUCTION

SIP-Italian Telephone Company, has decided to start with the process of automatization of the representative documentation of its telephone network.

For this reason they have organized a task-force of experts that have defined the specifications for the automatic drawing and for numeration of the telephone networks.

This paper is intended as a reference manual by which it is possible to set up the creation of the digital file.

After more than six months of work on the system, and having set up user oriented procedures and the other programs needed to satisfy specific requirements, the General Direction of SIP has decided to start the operative phase, providing a system not only for the Rome's office but also for Milan and Neaples.

SIP foresees to have the system operational by September'82.

SIP AND ITS CARTOGRAPHY

The cartographic documentation of the telephone network on which the system has been used, consists of:

- Planimetry map of the principal network of distribution and junction. This map, in scale 1:2000 or 1:1000 relates to the distribution network between the exchanger and the departements as well as the junction cables

- Planimetry map of the principal network
  At the same scale and same size as the map mentioned above. This map relates to the part of network distribution and network terminals

- Schematic map of pipe-lines sections
  This map relates schematically, to the characteristics of the work, the size and position of the cables installed

- Schematic map of the exchanger
  This map shows, for every station, the correspondence between the position of the going-out cables at the exchanger and at the opposite terminals

- Schematic map of the shared-lines cabinet
  With format A4, the map shows, for every cabinet, the corrispondence between the coming-in cables and their position in the exchanger. It visualizes the details of the junctions in the cabinet. Also included is a list of the distances between elements of the network

The maps referring to the first and second point are represented on the cartographic planimetric basis. These maps are up to date and in very good conditions presenting only the geometrical elements strictly necessary, hence making a good base for a digital data base structured in levels.

WHY SIP HAS DECIDED FOR THE AUTOMATIZATION?

The reasons that have induced the Company to start using the automatized systems, can be evaluated in terms of better efficiency during the course of the activities, and particulary with:

- Reduction of the on-call repair times due to cables damages, being able to intervene always with updated cartography

- The easy control of the inventory of the laid network for the certification of the reports of the contractor

- More precise determination of the network inventory

As far as the updating work and the production of the maps is concerned, the objectives of the company can be synthetize as follows:

- better operational simplicity
- less production time

DESCRIPTION OF THE OPERATIVE PROCEDURES

The operative procedure used by SIP is articulated, essentialy in the followings points:

- Acquisition of basic planimetries:
  a- the original map is read automatically with a scanner (Kartoscan)

  b- The scanned data is converted by a program into a vector form. The result is a digital representation of the original map. Fig. 1

- Acquisition and updating of telephone maps, schematic maps and selected data
  a- the maps are digitized manually into the system
  Fig. 2 - Fig. 3

The configuration of the system allows the symultaneous activity of multiple work stations, each consisting of one graphic screen for visualization and one digitizing table for coordinate surveying of the significative points on a draft (vertices, circles centers, etc.).

For the interactive work several tools can be used: light-pen, trackball, functional and alphanumeric keys, allowing easy access to macro-interactive functions, supplied with the basic system.

- Automatic drawing on the precision drafting table
  The drawing is carried out automatically on a precision drafting table, controlled directly from the computer.
  The drafting table is equipped with a head holding several interchangable pens, these can be ball-pen or ink type, with possibility of several colours and thiknesses.
  The speed of the table can be adjusted, depending on the type of ink used, until a maximum of 1 meter per second.

- The major functions of the interactive application software are:
  a- structuring of all elements in a multilevel data structure (planimetry, principal network, terminal network, etc.). These elements are graphically defined via their essential contents (coordinates, symbols, algorithms) which can be logically connected together.

  b- organization and merging of files is obtained via the automatic reading system (SIP uses this method only for the basis planimetry acquisition) c- powerful interactive editing of all elements

OPERATIVE RESULTS

As mentioned before, SIP aimed from the operative point of view,to achieve the best operative simplicity and the quickest production. Concerning production SIP has undertaken a time study of the activities related to traditional and automatic methods.

Obviously the ratio between the two times varies depending on the kind of documentation produced. The weithed mean has given the result of 1:5 (time for automatic drafting/time for manual drafting).

To produce all necessary maps related to a certain area of Roma, SIP found that it took 300 men hours using the computerized system, against 1500 men hours needed by the traditional manual method.

BENEFITS EXPECTED BY SIP FROM AUTOMATIZATION

To evaluate the return of the investment necessary for the realization of the centers for urban networks, we can refer to:

a- the quality of the product supplied by the system

b- the benefits that such kind of product may have on some operative activities

c- the costs for the automatized solution compared to the traditional one (1)

While the benefits deriving form a- and b- are hardly evaluable in terms of money, on the other hand point c- shows clearly that a return can be realized, not only in general terms of efficiency but also in terms of money.

As regards the quality of the product, the main aspects are:

- the flexibility of the digital data organization (graphical and numerical) that allows the absolute indipendence from the different scales, also permitting a more flexible approach to the maps structured with appropriate levels.

- better legibility of the cartography, compared with the one manually produced and a better approach to the standardization of the drawings.

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(1) The comparison with the traditional solution has been done only as a theoretical example. The traditional method has never given, in spite of all efforts made during past years,the desired efficiency.

- the absolute corrispondence of the inventories and of the indexes of the data shown on the maps

Other benefits derived from the availability of an up to date cartography, can be found in the following activities:

- planning: immediate availability of the real situation of the laid networks

- maintenance: increased rapidity and certainty for on-call repairs

- management of the potential users: exact location of the network terminals

Also we can foresee the possibility of utilizing the information provided by the system as input for management procedures relating to finantial problems.

At last, with regard to balance of costs versus benefits derived from the introduction of the system, we think it may be useful to give some evaluations on the amount of labour involved in updating cartography with system compared with the traditional one.

The evaluation has been carried out assuming both procedures to be fully operational.

Times involved were taken at the "Agency of Rome", during a test period of 4 months.

During this period of time several samples have been taken leading to a result of 1:5 ratio between automatized and manual method.

It was osserved that a draftsman manually updates a map at roughly 0.04 Kmcable per hour which gives us an extimate of 70 Kmcable per year.

As in one year SIP implements networks for about 30,000 Km cable, the draftsmen necessary for the updating work is approximatly 450.

On the other hand using the system, the number of draftsmen required is approximatly 90 persons, hence savings about 360 persons. At the cost of $ 19,000/year per draftsman, SIP may save as much as 360 x 19 = $ 6,84 million/year.

The equipment for CAD with 90 working stations needs as investment approximatly of 115,000 x 90 = $ 10,5 million to which corresponds, with depreciation allowance of 10 year and interest rate of the 22,5% an yearly cost of about $ 2,7 million to which we have to add 0,83 million for maintenance; the total result is $ 3,53 million. Therefore, using the system, SIP should get savings for $ 3,31 million per year.

Finally we must consider that it had never possible for SIP to dedicate the right amount of resources in updating maps;

the consequence is that today there is a large amount of backlog maps.

Today, we have strong reasons to think that SIP could reach its objectives of exact and precise updating of the maps of its network at fully operational conditions.

Fig.1

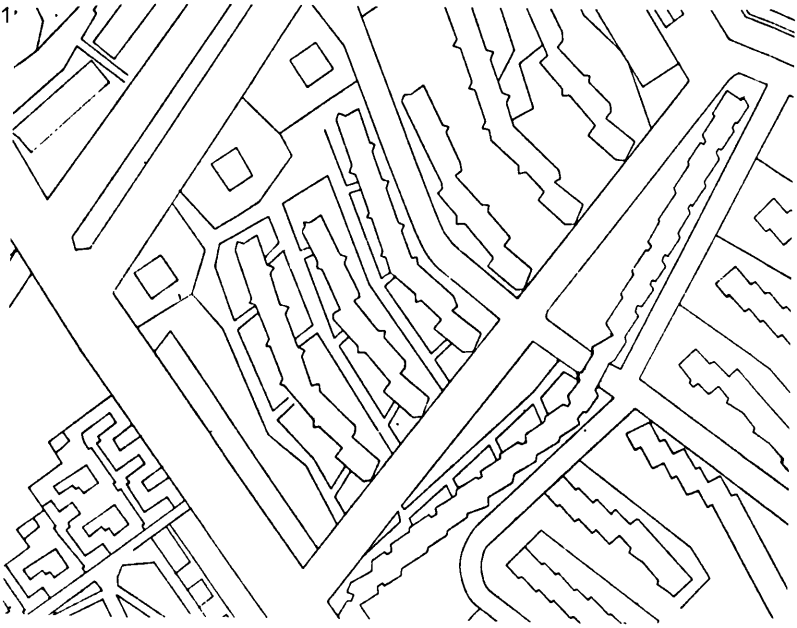


Fig.2

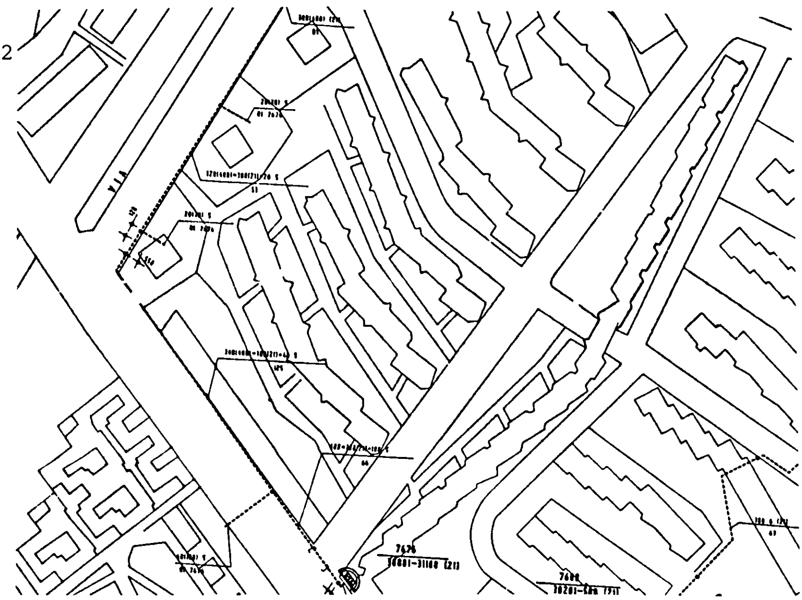
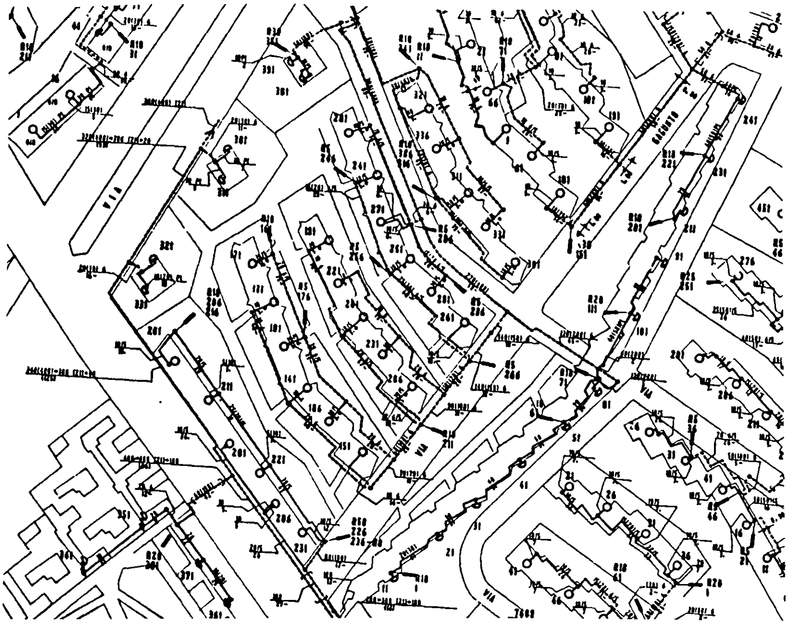


Fig.3



COMPUTER GRAPHICS AT THE UNITED STATES MILITARY ACADEMY

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ABSTRACT

The highly sophisticated Computer Graphics Laboratory (CGL) (Department of Geography and Computer Science) provides the United States Military Academy with a unique state-of-the-art environment for cadet and faculty participation in multilateral funded research projects. The Defense Nuclear Agency has asked the CGL to investigate the use of a plotter hard-copy device driven by an Apple II microcomputer to be used in conjunction with the Target Analysis and Planning System. The Defense Mapping Agency (DMA) and the Engineer Topographic Laboratories (ETL) are providing substantial economic and technical support to assist CGL personnel in identifying, demonstrating and testing military field applications of digital topographic data and digital data processing techniques. DMA has provided further funds for the purpose of comparing the information content of a low altitude multispectral scanner digital data tape to that of a conventional photograph. Work is being performed to assist in automating the terrain analysis procedure for ETL. Under the sponsorship of the US Army Institute for Research in Management Information and Computer Science and the Center for Tactical Computer Systems, the CGL is pursuing a program of applied research in the education of potential users of Ada, the recently accepted, DOD high-order language for embedded computer systems. In all cases cadet exposure to the research is maximized.

INTRODUCTION

The United States Military Academy has been involved in basic and applied research for many years. The Department of Geography and Computer Science (G&CS) has developed a research facility called the Computer Graphics Laboratory (CGL) with the mission of supporting cooperative research efforts with a number of Department of Defense and Department of the Army agencies. The CGL is a sophisticated installation consistent with its research activities, and an important adjunct to the educational program of West Point. Cadets, through courses of instruction, individual research projects and internships at various laboratories, have the opportunity to see and work with the latest technology.

Mapping, Charting and Geodesy (MC&G) serves as the unifying theme for the many disciplines in the Department. It was the recognition of this relationship which pointed the D/G&CS toward using the intellectual and technological resources available to enter into the broad field of computer graphics as applied to engineering and mapping.

For the past year two officers have been working full time on programs funded by the Defense Mapping Agency (DMA) and the United States Army Engineer Topographic Laboratories (ETL). The projects discussed in this paper are in the area of digital data exploitation and automated terrain analysis. A number of other projects are being done within the D/G&CS and will be explained in lesser detail.

FIELD EXPLOITATION OF DIGITAL TERRAIN DATA

This project has a number of objectives including experimenting with data base precision and formats, improving current capabilities to display terrain views and promoting the exchange of MC&G ideas among agencies, the Academy and other internal parties. One of the most important of the project objectives is to expose the technology of digital data exploitation to cadets and members of the military community.

Each summer the Department of Geography and Computer Science supports Cadet Field Training for Third Class cadets at Camp Buckner. In addition to supplying officers to conduct Land Navigation training, the Computer Graphics Laboratory provides computer support in the form of three-dimensional, computer-generated terrain views to include line perspective and oblique views. The algorithms for these programs were furnished by the ETL (Jancaitis 1975; Taylor 1979). Line-of-sight profiles and weapons placement plots are used to give the cadet a greater appreciation for the information on two-dimensional map sheets.

The simplest and most familiar of these graphics is the line-of-sight profile. The user may specify a particular data base to be used. Input prompts include coordinates of the endpoints of the line of sight, height above the ground at each endpoint, the number of samples to be taken between the endpoints and vertical exaggeration factor to enhance key terrain features. The result is a cross-sectional view of the terrain showing the endpoint coordinates and whether one is hidden or visible from the other. The actual ground distance is also given. This is a key feature since the distance may be as much as 20% greater than straight-line distance for hilly terrain. Although the cadets are familiar with hasty line-of-sight profiles, this rapid and accurate system introduces the possibility of applying line of sight (LOS) profiles by Signal personnel (LOS antennas), Artillery (positioning forward observers), Infantry and Armor (locating LOS weapons) and many others.

The line perspective view is another way to bridge the gap between the map and the actual terrain. The perspective view may be used to show cadets that in times of limited visibility or hours of darkness, it becomes important to determine what the terrain looks like from the information on the map. By selecting the observer's location, height above the ground and azimuth of interest, the computer is able to generate a view of the terrain depicting what would be seen if the observer were actually there looking in that direction. It is an invaluable training tool relating the three-dimensional terrain (ground) to the two-dimensional map. The perspective view is also important in gaining an understanding of slope. While the contour map gives indications of where steep and gradual slopes occur, the perspective shows the angles as one would see them on the ground.

The above principles are applied again when the cadet is taught to construct a hasty prospective view from contour lines and key terrain features. The oblique view is generated by placing a number of cross-sectional views from the LOS profile side by side. Like the perspective view the actual "role of the terrain" can be seen from this view. The observer is assumed to be at a distance of infinity from the terrain and an angle of 30 degrees from the horizon. The user can input the size (length by width) of the terrain to be used and the viewing azimuth. Unlike the perspective view, actual horizontal distances are easily measured from the oblique view creating a kind of relief map to which the cadet can easily relate. By increasing the vertical exaggeration option, key terrain features are enhanced as in the other views. The cadet can readily determine where terrain will mask the view of an observer or prevent engagement by a LOS weapon.

All soldiers are concerned with selection of positions for direct fire weapons. The weapon's placement plot shows the coverage for a particular weapon giving characteristics such as left and right limits, range and height above the ground. The user selects the location and size of the area of interest and the contour interval to be used. A contour map of the area is drawn and a location is selected for the weapon. The coverage diagram is computed and drawn as an overlay.

These programs have been beneficial to the Land Navigation instruction. A survey completed this summer indicates the majority of cadets were able to better understand the information on their standard map sheets after having been exposed to the graphic displays.

While this training has been conducted for the past three years, this year for the first time the graphics displays were generated directly from the computer instead of using a "canned" presentation from tape. The link was made using standard tactical FM radios over a distance of approximately 8 miles and was tested at a 2400 baud rate. Additional communications equipment would permit the test system to operate at 9600 baud. The plan for next year is to expand the program to use a microcomputer to generate the map products in the field as needed by the soldier. The communications link would allow access to large data bases stored on the host computer.

AUTOMATED TERRAIN ANALYSIS

The CGL, in support of funded research for the Defense Mapping Agency and the Engineer Topographic Laboratories, has been investigating the problems concerned with implementing an automated terrain analysis system. The overall research efforts are designed, first, to address the possibility of multispectral digital data replacing the photograph, and, second, to discuss the problems in identifying and classifying that terrain which may be of concern to the military commander.

The purpose of this section is to describe the apparatus and classification system at the CGL, discuss the results of some preliminary tests and relate these results to conclusions drawn by other research personnel.

Classification System.

Landsat scenes are displayed on the CGL's DeAnza VC 5000 color image processing system which is driven by a VAX-11/780. Initially a complete Landsat scene (approximately 185 km on each side) is displayed on the screen. The viewing of the complete scene is made possible by selecting every 7th row and column of the digital data purchased from EROS.

Should the analyst desire to display every Landsat pixel he may do so by moving a cursor to the selected area and having the scene redrawn. The DeAnza has the capability to display 480 by 512 pixels.

The operator may utilize the DeAnza's hardware zoom (8X magnification) feature to examine a scene more closely. When the scene has been studied and the analyst is ready to gather training samples he has two options, record them individually or in rectangular groups.

Gathering training samples from small fields such as isolated swamps, roads, etc., necessitates being able to look at and record the brightness values of individual pixels. A specific area in the scene is selected and the DeAnza's 8X zoom capability enabled. The analyst then moves a cursor inside the now large image pixel and instructs the computer to record the Landsat brightness values in all four bands. The only requirement here is that the programmer ensure that his system housekeeping is sufficiently precise to allow the recording of the brightness values from the proper pixel (after selecting, zooming, scrolling and densifying).

When the areas of concern are large, it is beneficial to use a variable size box cursor and record all values inside the box.

After gathering the training samples the analyst computes the mean, variance and smallest and largest values in all four bands. He may also choose to have the scatter diagrams of any two bands drawn on the screen at any one time or to draw the histogram of his training sample in each band. At this time the analyst has the option of rejecting the training samples and repeating the collection procedure.

Once the training samples have been gathered and accepted the system will search for all similar terrain. An interesting feature is the ability of the operator to have the system classify just within a movable, variable size box cursor. This provides the opportunity to select features to be "compared" against the training sample, allows for flexibility and versatility, and greatly shortens the classification time. Computer time is not being wasted applying the decision algorithm to displayed pixels for which the analyst has no interest. All pixels which are considered to be of the same class as the training sample are displayed in a distinctive color.

The modularized system will permit the easy installation of any classification algorithm. Although a probabilistic decision strategy has been used extensively, the parallelepiped rule is presently being utilized because of its simplicity and speed. A necessary step when using a probabilistic decision rule is to establish a threshold value. When identifying one type of terrain from the whole scene the selection of the threshold value becomes an experimental exercise with the analyst slowly iterating toward the parallelepiped decision rule (Thompson 1982b).

Experimental Design.

By using maps, CIR photography, and personally gathered ground truth data, landcover overlays at scales of 1:250,000, 1:50,000 and 1:25,000 were prepared of a region in the vicinity of West Point, New York.

The purpose of the experiment was to study whether, after selecting proper training samples of several classes, could the automated terrain analysis system, using Landsat data and a spectral classifier, identify/classify all similar terrain? The classes tested were urban, impervious, non-forest vegetation, water and swamps. The system was evaluated both in total area and site location and was compared to the landcover classifications at all three scales.

Table 1 shows the number of plotted locations at each scale found within the ground truth area. Naturally when making a map at a scale of 1:250,000 fewer distinct terrain features will be plotted by the cartographer than would be plotted at 1:25,000. It was hoped that the Landsat classification would show a pronounced greater similarity to one particular classification scale.

The area covered by each class was measured at the three scales and compared to the area located from using the Landsat data (number of pixels times the area of each pixel).

The number and site of each feature was compared by making an overlay of the screen after each classification.

Experimental Results.

Repeated tests encompassing myriad conditions led to the same conclusion--Landsat data does not allow for accurate discrimination of the above classes in the type of terrain found in the Hudson Highlands.

The Landsat automated system found 26 water bodies (certainly the easiest feature to locate) which corresponded in number to the 1:250,000 classification. However, the area varied so widely the entire operation was suspect. The other features varied tremendously in number, area and location (errors of location were the result of varying classification errors, not planimetrically mislocating the item) (Thompson 1982b).

The results of this test, although disappointing, are compatible with what one might expect from this rugged, dense, mountainous region composed of small lakes, small swamps, underbrush, rock, tall grass, etc.

"An automated terrain analysis system based on Landsat data as presently configured is not possible in terrain of this type and probably not possible anywhere" (Thompson 1982b). Schreier, et al. (1982) point out that "Relatively few computer-assisted land classification methods based on multispectral Landsat data have become operational...." The primary reason offered by them was because of the "...complexity of the spectral data and the limited ground resolution of the Landsat multispectral scanner" (Schreier et al. 1982). Vogel (1977) stated that Landsat data is inadequate for classifying most of the basic terrain elements. This statement came at the conclusion of a meticulous study in which Landsat data was examined to see if it could meet the needs of a large number of cartographic, mapping and terrain requirements. Out of over 300 subcategories the requirements for only 2 could be met by Landsat data. Gordon (1980) concluded after an experiment in Ohio "...that substantial errors are associated with use of Landsat data for land cover and change analysis," and Sharp (1979) suggested "...that too much is being expected from the Landsat demonstration projects."

High Resolution Data.

Tests have been conducted at the CGL using low-altitude, high-resolution multispectral digital data collected by Daedalus Enterprises Incorporated over an area in southeast Kansas. Pixel size is approximately 12 feet on the ground with data being gathered in 5 bands (blue, green, red, infrared and thermal infrared). At the same time that the 5-band multispectral digital data was being gathered, overlapping color infrared and color photographs were taken. This data provides an excellent base on which to build an evaluation of an automated terrain analysis system.

It was revealed that a spectral classifier alone could not accurately classify the terrain, even with high resolution data, because seemingly homogeneous features were often statistically nonhomogeneous (Thompson 1982a). The automated terrain analysis system of the future will have to employ "smart software" which will make contextual, tonal and textual decisions in conjunction with a straightforward spectral separation.

The Future.

Despite difficulties and set backs the future will demand digital data. "Three fundamental driving forces underlie a shift at DMA towards a reliance on digital data bases for mapping, charting and geodesy operations. These are the need for product flexibility, the need for responsiveness, and the need to reduce production costs" (Williams 1980).

Leighty (1979) after discussing our current problems said, "We should expect that highly automated systems for information extraction from aerial imagery will be a part of our production capabilities in the future...."

Improvements may be expected through better resolution, improved hardware, contextual, tonal and texture analyses, more sophisticated modeling, multitemporal data, greater use of the electromagnetic spectrum, more detailed definition of the parameters involved, and countless other innovative approaches.

TABLE 1. Number of plotted terrain features at three scales in the ground truth area.

Feature	1:250,000	1:50,000	1:25,000
Water Body	23	60	68
Swamp	0	22	47
Impervious	5	19	56
Urban	5	10	21
Vegetation (non-forest)	15	23	28

OTHER PROJECTS

Environmental Early Warning System (EWS).

The United States Army Construction Engineering Research Laboratory (CERL 1980) in Champaign, Illinois, developed the prototype of a computer program designed to allow "...decision makers and environmental specialists to rapidly determine whether proposed mission changes can be expected to result in unacceptable environmental impacts at affected installations." Although not an Environmental Impact Assessment or Statement, the program defines a series of analyses and graphical displays (Environmental Early Warning System) which "...provide preliminary notification of certain potentially serious environment-related problems at very early stages of project planning." In essence, it is a system designed to respond to "what if" questions, that is, questions which ask "what if this battalion, school or activity were moved from installation X to installation Y?"

CERL recognized that the line printer graphical output of its prototype lacked detail and sophistication. Computer Graphics Laboratory personnel were asked to make EWS operational on the Department's VAX-11/780 minicomputer and integrate the system with a modern graphical analysis package so better quality display graphics could be produced. Two modules of Odyssey (Polyps and Prism) were purchased and made operational. While recognizing that current problems prevent the purchase of further Odyssey modules, it is the intention of the CGL, using other graphics display systems or different techniques, to amplify and embellish the graphical output of EWS. Currently work is being done to determine the suitability of low-cost raster based plotters (Tektronix 4612, ACT-1 Color,...) as output devices. Concurrently, the problems involved with changing the display from raster to vector output are being investigated.

Army Housing Management System.

A second project accomplished for CERL provided an opportunity for considerable cadet participation. The overall mission was to gather information and make recommendations to expedite the eventual implementation of the Army Housing Management System (HOMES). The formidable task of HOMES is to allow for the automated management of the very extensive real property family holdings of the United States Army. The housing functions were divided into thirteen categories with the cadets enrolled in EF 383, Management Information Systems, being instructed to conduct a systems analysis of the planning, programming, and budgeting and the finance and accounting functions. In addition to the benefits of having the cadets learn firsthand the challenge encountered in performing a systems analysis, a complete documentation of these two functions was achieved. The student initiated identification and step by step documentation of the interrelated functions facilitated recommendations for automating the system. Specific recommendations are not presented here but, in general, they concerned item definition, suggested design of an integrated data base and suggestions as to which functions could be automated. In a follow-on effort, cadets enrolled in EF 483, Data Base Management Systems, were involved in a course project which produced a detailed definition/description of the specific data items identified in the systems analysis. In a related effort another cadet, in an individual study project identified and extracted data items from the Standard Army Multi-Command Management Information Systems (STAMMIS) for use in HOMES. Specific missions included writing a COBOL program to extract data items from STAMMIS and the transfer of data from the VAX-11/780 to the AM-100 computer.

Ada Technology.

Under the sponsorship of the U.S. Army Institute for Research in Management Information and Computer Science

(AIRMICS) and the Center for Tactical Computer Systems (CENTACS), the Department is pursuing a program of applied research in the education of potential users of Ada, the recently accepted, DOD high-order language for embedded computer systems. The research effort has involved the development of an elective level, one-semester course entitled "Ada Concepts and Programming" which was taught to a select group of ten computer science concentrators. Ada/Ed, an Ada translator developed at New York University for CENTACS, which runs on the VAX-11/780, was used in support of the course to provide "live", hands-on programming capability. Three of the cadets enrolled in the course continued in the second semester with a team research project to investigate transition methods which can be used for new Ada programmers. Ada has been taught as a regularly offered elective course since the Second Semester, Academic Year 1981-82. The CGL is continuing to participate in Ada related projects, to include the Ada Training and Education Committee of the DOD Ada Joint Projects Office, a CENTACS evaluation of proposals to redesign two existing military embedded computer systems in Ada and the Air Force Ada Programming Support Environment (APSE) Design Evaluation.

Target Analysis and Planning System (TAPS).

The CGL has been asked by the Defense Nuclear Agency to develop a driver for a plotter hard-copy device driven by an Apple II microcomputer in support of TAPS. The project was completed in June of this year. In July a module was written which provided a flexible world-wide capability to transfer between Universal Transverse Mercator (UTM) grid coordinates to Cartesian coordinates referenced to an operator determined origin. This module will enable the TAPS program to be used world-wide instead of being confined to Europe as it has been for the past three years. The module takes into consideration the curvature of the earth and changes constants used to convert between UTM and Cartesian coordinates to accommodate the user's particular spheroid.

CONCLUSION

One can easily see that the volume of work done by the CGL is more than two researchers can accomplish alone. Much of the work is done by cadets through summer intern assignments or special topics courses offered under the supervision of the research officers. Other projects are accomplished through the volunteer efforts of full-time faculty members. The mission of the CGL remains clearly to expose the cadets to the current technology. The reward to the agencies who support the CGL is the energy and enthusiasm the cadets and faculty supply in meeting the challenge of this new technology.

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COMPUTER-ASSISTED FEATURE ANALYSIS FOR DIGITAL LANDMASS SYSTEM (DLMS) PRODUCTION AT DMA

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ABSTRACT

The Defense Mapping Agency produces digital feature and terrain elevation data. These data are combined to form the Digital Landmass System (DLMS) which is used to support advanced aircraft simulators and navigation systems. Recent technical acquisitions are being implemented to improve digital feature production methods. This paper discusses the transition from labor-intensive, manual production methods to computer-assisted distributed data processing methods. On-line data entry, real-time data validation, LANDSAT digital image processing applications, computer-assisted analytical photogrammetric stereo-plotter systems for feature extraction, interactive data editing, quality control procedures and sensor simulation systems are presented. Research and development efforts in the areas of all-digital production systems are also discussed.

INTRODUCTION

The Defense Mapping Agency produces Digital Feature Analysis Data (DFAD) and Digital Terrain Elevation Data (DTED) which when combined form the Digital Landmass System (DLMS). The DLMS data contains terrain, landscape and cultural information required for the support of advanced aircraft radar simulators, automated map/chart production and navigation systems for aircraft. The digital data are used by Department of Defense Agencies, NATO countries, and by DMA as ancillary source for other production programs.

Considerable attention has been given in literature and symposia to the concepts associated with the digital collection and storage of elevation data into arrays commonly referred to as "Digital Terrain Model" (DTM). The DTM contains three dimensional information (ϕ,λ,h) in matrix form describing the terrain relief in the DLMS data. The encoded physical description of the surface of the DTM is contained in the DFAD. The production of this latter data has received very little attention at previous technical symposia. The reasons for this were not due to a lack of concern; indeed, the academic community, private industry and government agencies have been actively seeking new technologies applicable to feature analysis production since the DLMS program began in 1972. To date, however, production procedures have remained relatively unchanged and are based on large, manual, labor-intensive tasks involving stereo photointerpretation using zoom stereoscopes, hand-held calculator measurement computations, manual preparation of textual data and graphic compilation of feature manuscripts.

This paper deals with advances made in the areas of DFAD production techniques, some of which are already implemented, some to be implemented in the near term (1982-early '83) and others in various stages of technical development.

Improvements to the DFAD production process follow a staged progression towards automated systems. The progression begins with the semi-automated production of landscape features using digital image processing techniques on LANDSAT Multispectral Scanner (MSS) imagery. Secondly, during 1982 interactive data entry terminals will be introduced into the analyst's work station to allow in real-time: textual data entry, on-line DLMS specification definitions, quality control and measurement transformations. Also, in 1983 a phased implementation of computer-assisted stereo analytical photogrammetric compilation systems will allow for direct digital production, eliminating manuscript compilation methods and off-line textual data processing when the full complement of systems are in place.

Additional quality control and editing of DLMS data will be accomplished using an interactive image processor, the first copy of which was delivered in June 1981. The Sensor Image Simulator (SIS) allows the generation of scene displays of DLMS data in a number of different formats including perspective views, contours, shaded relief, and sensor simulation displays. Direct interfaces with either the terrain or feature data files in a variety of display formats can be accomplished. Long-term studies are underway in the interest of automated feature analysis, especially in the area of digital image processing methods including interactive feature extraction techniques, applied pattern recognition studies and machine intelligence. The DMA is currently conducting specific studies to determine the feasibility of all-digital production systems. Digital image processing test facilities have been recently installed at the Aerospace Center and the Hydrographic/Topographic Center and are being used for these pilot digital investigations. A review of each of these initiatives will follow, describing what DMA hopes will lead to the successful implementation of these new and improved technologies into the production process.

DIGITAL LANDMASS SYSTEM

The DLMS contains two major types of data, elevation data and physical feature data. The terrain data are stored as a matrix of elevations (Figure 1) referenced to mean sea level and are recorded to the nearest meter. Horizontal positioning is described by specific latitude-longitude locations. Spacing or density of the elevation arrays is in whole second intervals depending on collection level requirements.

The associated feature data file holds digitally encoded descriptions of culture and landscape features within the terrain region. Most feature types are represented by polygonal boundaries and descriptor tables (Figure 2). The table includes coded information such as surface type (e.g., forest), predominant makeup (e.g., deciduous trees), and average height. Some features such as bridges, dams, walls, and pipelines are specified by line segments, while others, such as towers and certain buildings are specified as point locations with feature heights included. Header records containing index and reference information are used to relate descriptive information to corresponding geographic locations of features. Detailed DLMS data content is described in reference 4.

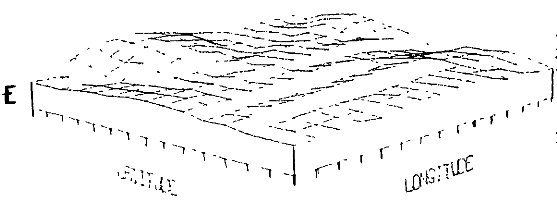
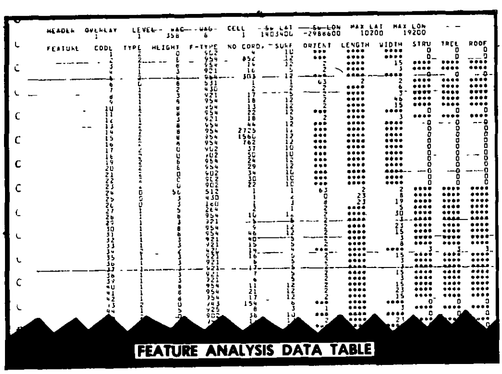


Figure 1. Digital Terrain Data shown in 3-dimensional perspective: Elevations for each (ϕ, λ) intersection are stored in meters above mean sea level.



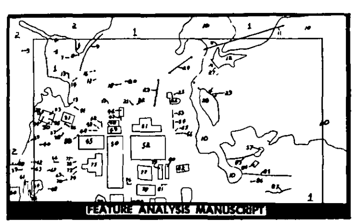


Figure 2. Digital Feature Analysis Data.

Digital Terrain Elevation Data (DTED)

The DTED is a matrix containing elevations at every grid intersection (post). The production of this data is accomplished by photogrammetric or cartometric methods. Considerable attention to the methods associated with DTM production has been given in literature and is not within the scope of this paper[1]. Production techniques for DTED within DMA will be summarized briefly here.

Photogrammetric methods are used to collect nearly all terrain relief compiled for the DLMS in DMA. Advanced distributive computer-controlled analytical stereo-plotters are tailored to the process of establishing oriented stereo models and recording model coordinates by either manual or machine correlation (Figure 3). Collection of relief information from the model is either along regularly spaced profiles or along terrain features (geomorphic data). Interpolation of collected elevation data yields a uniformly spaced grid of elevations in accordance with DLMS specifications for DTED[2].

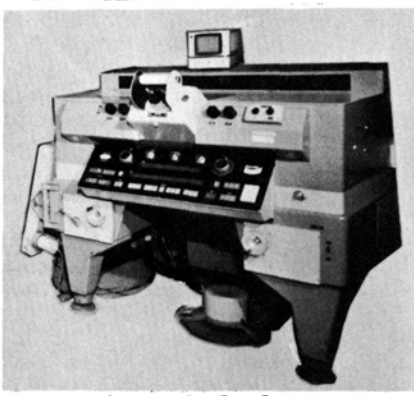


Figure 3. Analytical Stereo-plotter for Terrain Data Production Based on Stereo-Profiling Techniques

Cartometric methods for DTED production are based on automated raster scanner (Figure 4) collection of map/chart contour manuscripts. Similar to photogrammetric methods, interpolation algorithms for converting vectorized raster contour data to final DTED matrix form are based on weighted radial averaging methods for points surrounding matrix posts. Contour data is likewise enhanced with geomorphic information (e.g., stream beds, ridges, etc.) to preserve the integrity of terrain forms[3].

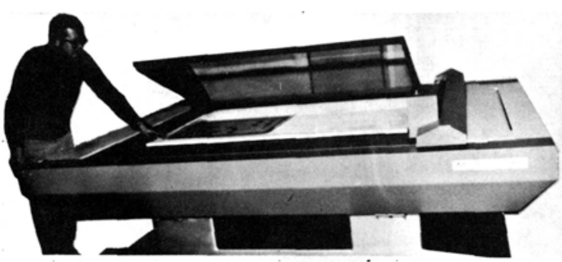


Figure 4. Automated Graphic Digitizing and Editing System (AGDS) for collecting DTED from Cartographic Sources and Digitizing DFAD Manuscripts

Digital Feature Analysis Data (DFAD)

The DFAD describes the physical characteristics of the three-dimensional surface described by the DTED. Features selected for inclusion are determined by factors outlined in product specifications[4]. Factors include such considerations as size, predominant height and type of surface material. This information is extracted primarily from aerial photography with collateral sources including maps and textual materials.

All features are identified by a unique number, feature type (areal, linear, point), surface material category (e.g., metal, concrete, earthen, trees, water, etc.), predominant height, and feature identification (e.g., industry, agriculture, institutional, storage, landform, etc.). These identifiers and other characteristics, depending on feature composition, are of paramount importance in the structure of an emerging data base capable of supporting radar simulation in particular. Additional characteristics include identification of tree, roof, and structure density, dimensional and orientation data for certain features and world geographic reference cell data. These characteristics are described by number codes and stored in the data base.

The feature analysis production task is entering a transition stage, advancing from current manual and associated analog, off-line processing to distributed data processing systems. These systems introduce real-time, on-line, remote work station concepts and are based on analytical photogrammetric methods and digital image processing techniques for semi-automated feature extraction, interactive editing, quality control, and sensor simulation. This transition will be the subject of the remainder of this paper.

First to review the current DFAD production task - Procedures are manual-based, labor-intensive tasks described by stereo-photo interpretation of aerial photography using unaided binocular zoom stereoscopes. Line manuscripts are drafted on light tables and feature descriptor data are recorded on coding sheets for subsequent off-line processing. The manuscript is digitized on a flatbed scanner (Figure 4) and resultant line vector information and descriptive data are merged and reformatted.

OVERVIEW OF DFAD PRODUCTION IMPROVEMENTS

DIMIAS

The first steps to improve/enhance the DFAD production process were the results of initiatives taken in 1975 which identified and ultimately effected the acquisition of the Digital Interactive Multi-Image Analysis System (DIMIAS). This equipment (Figure 5) is used primarily to analyze and extract landscape features from digital imagery in a semi-automated mode. The primary application is for rural/remote areas, opposed to urban areas. The system combines the analysis and digitization operations for landscape features. The requirements for the feature analysis and digitization processes are essentially the same as for manual methods: registration of digital imagery to geodetic control, analysis of imagery, mensuration, definition and relational location of features in accordance with DLMS specifications. Processing includes digital registration, image correction, image enhancement, image classification, mensuration and transformation functions. The input imagery is LANDSAT MSS digital data; the output is DLMS digital data for landscape features. Trial production of several one-degree cells was accomplished in 1981. The process of merging DIMIAS-produced landscape data with manually compiled cultural feature data for a given production area was found to be inefficient.

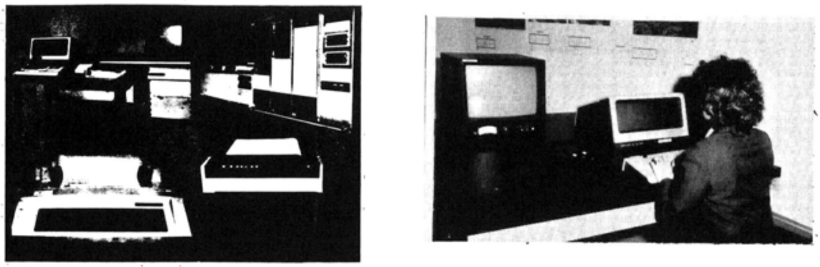


Figure 5. Digital Interactive Multi-Image Analysis System for semi-automated Landscape Feature Extraction from LANDSAT MSS Digital Imagery.

Tests were recently completed investigating low resolution, DLMS-type data compiled exclusively from LANDSAT materials using DIMIAS image processing techniques. These data would be used for high altitude, low resolution sensor simulation in areas of low cultural densities and where photogrammetrically derived DLMS data has not been produced.

The potential applications of LANDSAT "D" to DLMS, other auto-carto methods and charting programs are being investigated using simulated LANDSAT "D" digital data and image processing approaches on DIMIAS.

IFASS

The Interactive Feature Analysis Support System (IFASS) is a mini-computer based system to be used for remote data entry, dimensional computation and data validation for DFAD descriptors. The system introduces CRT terminals into the current work station (Figure 6) and allows the feature analyst to

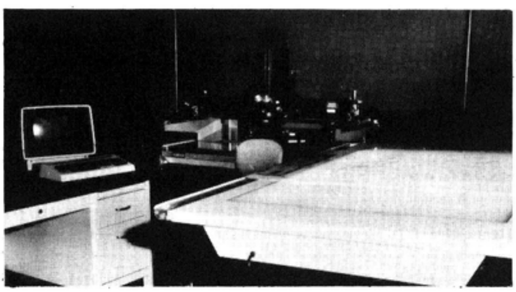


Figure 6. IFASS Work Station Configuration

interactively enter required descriptors as each feature is compiled. As each feature is identified, the IFASS will request, in a logical sequence, the entry of the required descriptive data. Acceptable values for each descriptor will be displayed on the work station video display terminals (VDTs) to ensure the entry of valid data. Errors detected by the software are immediately displayed on the VDT and replacement data is requested. Validation software is being developed by DMA personnel. The cost of the system is projected to be recovered due to consolidation, elimination and streamlining of data entry operations. The IFASS, scheduled for production interface in 1982 is the first distributed data processing system to affect the entire DFAD production work force. The IFASS will also allow for real-time interactive management information system (MIS) data and the storage and retrieval of production related statistics.

CAPI

Further extensions of the transition to state-of-the-art methods for DFAD production will be realized with the implementation of the Computer-Assisted Photo Interpretation (CAPI) System. The delivery of the first of a series of systems will begin in August 1982. This distributed processing system is an analytical stereo-photogrammetric, feature extraction digital-compilation system. It will consist of stand-alone image analysis/compilation stations supported by central processing facilities to perform required pre- processing and post-processing tasks (Figure 7). The basic

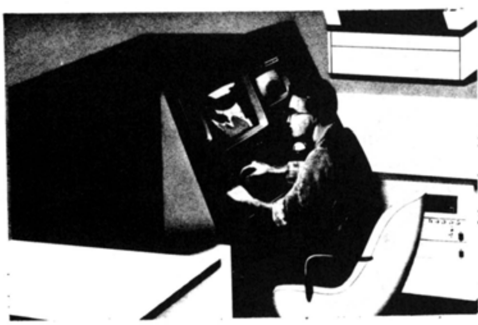


Figure 7. Computer-Assisted Photo Interpretation (CAPI) Work Station. Stereo model is computer-maintained and viewed with cross-polarized glasses.

function of CAPI is to extract all DFAD such as landscape, drainage and cultural features analytically from stereo imagery of all types.

The CAPI work station under microprocessor control will provide the image analyst the interactive capability to establish, view and interpret an analytically maintained stereo-model. The stereo viewing system design is based on cross-polarized screen presentation viewed with polarized glasses. The CAPI is designed to allow the analyst to measure required ground dimensions/areas, interactively enter and validate feature description data, digitally compile features in the stereo model, generate a digital feature file and view the compilation results on a graphics display. CAPI central processor(s) will support the work stations by performing pre-processing for absolute stereo-model orientation and post-processing to transform the work station digitized feature coordinates into geographics. The central processor will manage (store/retrieve) compiled stereo-model data, merge the compiled models to form a digital data set and generate plots of the digital data.

Implementation of this system will potentially replace manuscript compilation as well as off-line descriptor data processing. DFAD production will, at this point, be on a par with DTED production in the concept of analytical systems for film-based imagery. Predicted cost savings for CAPI are 20%. Efforts are underway to enhance CAPI stereo-model controls by introducing DTED into the DFAD compilation process. Elevations from the DTED can be used with single image coordinates to compute, in real time, the coordinates of the conjugate image. The introduction of this concept will allow three-dimensional control of the CAPI stereo-model. The substitution of DTED for "Z-wheel motion" to clear X-parallax will simplify the analyst's task to merely tracing out DFAD features. The floating mark will follow the terrain as defined by the DTED, allowing the analyst to stereoscopically view the relief model during DFAD compilation to assure the commonality and integrity of the total DLMS product.

The implementation of the CAPI system represents a complete transition from cartometric methods to analytical methods for DFAD production and presents a real challenge as analysts face the task of learning to operate this new DFAD production system.

SIS

The Sensor Image Simulation (SIS) System serves as a powerful tool to assure the adequacy and accuracy of digital data base products. The system is an integrated stand-alone facility with the necessary hardware and software for interactive, on-line data evaluation and correction. High speed array processors allow for display and interactive editing of terrain data in either shaded relief, contour or profile presentations. DFAD can be separately displayed and feature outlines can be moved or changed interactively. On-line transformations are performed to combine terrain and feature data, to assign reflectivity potential to features, and to display and edit either feature or terrain data in perspective view format. Finally, sensor simulation is performed by modeling electronics of actual sensor receivers and controls for a variety of sensors. For example, advanced aircraft radar models can be simulated from the DLMS data by describing the proper display geometry and format. Atmospheric conditions and receiver parameters (e.g., beam width, gain, altitude, range, etc.) can be varied to obtain particular simulations. The operator is able to interact with and edit results of this final simulated image. These digital image processing capabilities will significantly improve quality control methods for DFAD production processes and indeed offer new avenues for editing the DLMS product using interactive methods[5].

CPS

The Clustered Carto Processing System (CPS) is scheduled for installation in early 1983. The CPS will be designed to provide a set of interrelated automatic and interactive functions to accept digital data from AGDS, CAPI, DIMIAS, IFASS and SIS and perform various transformations on the data. These transformations include geometric/geodetic transformations; merging and panelling operations; editing, correcting, validation and output formatting. Hardware designs are based on two 32-bit super mini-computers for processing and one super mini serving as an edit subsystem. Communication lines allow data transfer and system back-up. Shared and local disk data storage pools total 2,304 megabytes.

ALL DIGITAL SYSTEMS

Studies were completed by DMA in the field of digital image processing, which focus on investigations of the applicability and feasibility of all digital production systems[6,7,8]. Additional Pilot Digital Operations (PDO) studies are the Interactive Feature Extraction Study and Applied Pattern Recognition Testing. These studies will be carried out on a digital image processing test facility called the Remote Work Processing Facility (RWPF). The RWPF is equipped with image manipulation and graphics processing algorithms (including some pattern recognition schemes and machine intelligent control structures) as interactive operations to aid in detection/identification, classification, delineation and digital recording of features. Experiments will be conducted on the RWPF to aid in the definitions, specifications and configurations of future digital production equipment.

IFAPS

The Interactive Feature Analysis Production System (IFAPS) will be a semi-automated feature extraction system. The emphasis on this initiative is based on technologies expected by mid '83. Extraction of some feature types will be automatically accomplished from digital imagery.

SUMMARY

The DMA is continually seeking to improve methods and accuracies of DLMS products. Feature analysis production is currently entering a period of transition from manual, carto graphic off-line methods to analytical on-line methods based on computer-assisted processes. Semi-automated extraction methods for landscape features can be accomplished by DIMIAS. Remote, interactive data entry terminals with real-time data base interfaces (IFASS) are being used to replace manual data preparation methods and off-line processes. CAPI systems will be phased in over 1983-1986 displacing both manual descriptor and manuscript preparation in favor of analytical-photogrammetric on-line production of direct digital data. Sensor simulation technology through SIS systems will enhance DLMS quality control/edit capabilities and assist in definitions of product requirements and potential DLMS applications. Studies in the field of digital image processing with applications toward computer-assisted feature extraction methods help define DFAD production systems of the future.

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DIGITAL TERRAIN ANALYSIS STATION (DTAS)

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BIOGRAPHICAL SKETCHES

CPT Thompson received a B.S. degree from the United States Military Academy in 1973 and was commissioned as a military officer in the U.S. Army. He has served in infantry assignments in both Europe and the United States and is a graduate of the Infantry Officers Advanced Course. In 1981, CPT Thompson earned an M.S. in Photogrammetry and Geodesy from Purdue University and is currently assigned to the U.S. Army Engineer Topographic Laboratories as an R&D Coordinator.

Mr. Socher is a Senior Programmer/Analyst for the IIT Research Institute. He earned a B.A. in Mathematics from St. John's University at Collegeville, Minnesota in 1967. During his career, Mr. Socher has developed a broad base of knowledge in automated data processing for cartographic/terrain data. For the past five years, he has served as project manager guiding the design and development of interactive/batch graphics software on the Digital Terrain Analysis Station (DTAS) for the U.S. Army Engineer Topographic Laboratories.

ABSTRACT

Battlefield commanders in today's Army need timely, accurate terrain analyses. Modern tactical realities do not give the commander time for manual preparation of map overlays and other graphic products from varied and voluminous sources. The commander must have up-to-date graphic displays and overlays highlighting tactically vital terrain features and battle/combat advantages resulting from terrain configurations. These factors, combined with the advances in computer technology and data base management, indicate that a computer-assisted terrain analysis capability is feasible and needed by the Army.

The terrain analysis capabilities under development on the Digital Terrain Analysis Station (DTAS) at the U. S. Army Engineer Topographic Laboratories will be such a system. The terrain analysis capabilities of the DTAS produce graphic products that fall generally into two major areas: Intervisibility and Mobility. The products may be displayed on the DTAS viewing screens or drawn to scale on the DTAS plotter. They may stand alone or be used in compiling other products.

The intervisibility capabilities are used to determine areas that are visible, either optically or electronically, from a given site. These capabilities have the user-selectable option of including vegetation heights in the analysis. The mobility capabilities are used to evaluate the potential effects of terrain upon friendly and enemy operations.

INTRODUCTION

Today's modern Army, with greatly increased emphasis on mobility and quick reactions, is becoming more and more concerned with the problem of supplying information about the battlefield to the commanders who must direct high-speed maneuvers on what has come to be known as "the extended battlefield." The commonly projected short duration conflict in Central Europe is one example of a situation in which it is feared that conventional terrain analysis techniques might provide information to combat commanders that is "too little, too late". The recent British involvement in the Falkland Islands is another prime example. Major efforts were required to assimilate a wide variety of source data needed to update the few existing maps available and to provide meaningful terrain analysis products. All this had to be accomplished in the short time available as the British landing forces steamed southward toward the Falklands.

Given the present state-of-the-art, digital automation appears to offer the main hope.

OBJECTIVE

The primary objective of the DTAS effort is to provide the terrain analyst an automated tool so that he can better meet field commanders' terrain information needs in terms of response time, flexibility, and accuracy.

MANUAL VS. COMPUTER-ASSISTED

Manual methods in use today are labor intensive and require a considerable amount of skill and experience. Products are produced based upon the assumption of various terrain and weather conditions. To change any of the assumed parameters, such as season or vehicle type, in most cases requires a complete reconstruction of the required product. Accuracy is not only dependent on the analyst's source material, but upon his skill and experience as well.

By providing him with an automated tool, his production speed can be considerably enhanced. If input parameters change, new products can be generated with relative ease. While automated methods are still directly dependent upon the accuracy of the source material, products are generated by the system and are therefore not as susceptible to human error. This frees the analyst to concentrate more effort on updating and refining the data base and evaluating system products.

The first step in the manual method is to assimilate the source data into a series of transparent factor overlays, keyed to a particular map sheet. By visually correlating the factor overlays in a sequential process, the analyst next produces one or more factor complex maps. Applying basic analytical models, the factor complex maps are again visually correlated to produce a final product manuscript.

The primary focus of the DTAS effort is to automate the task of correlating the various factor maps, applying the analytical models, and producing the product manuscript (see Figure 1). The factor maps exist in digital form as the data base. Ideally, the data base will be produced by the Defense Mapping Agency and then further updated in the field on the DTAS, as required. Typical elements which are contained in the data base are slope, vegetation, soil, urban areas, roads, railroads, waterways, water bodies, and obstacles. A distinct advantage to automating this portion of the process is the flexibility provided to the analyst. For example, to produce a Cross-Country Movement product for two different types of vehicles manually would require considerable duplication of effort. With an automated system, the operator needs only to change the relevent vehicle parameters and the system can then duplicate the task more quickly and with greater accuracy. Final product manuscripts can be plotted automatically to any scale desired.

In addition, the operator can interactively update the data base itself. Common changes such as construction or destruction of roadways and bridges, the creation of obstacles, and large scale defoliation can drastically modify the complexion of the battlefield. These changes can be made to the data base quickly and easily on the DTAS. Hence, final analysis products can be produced which are current and are of greater value to the field commander and his staff.

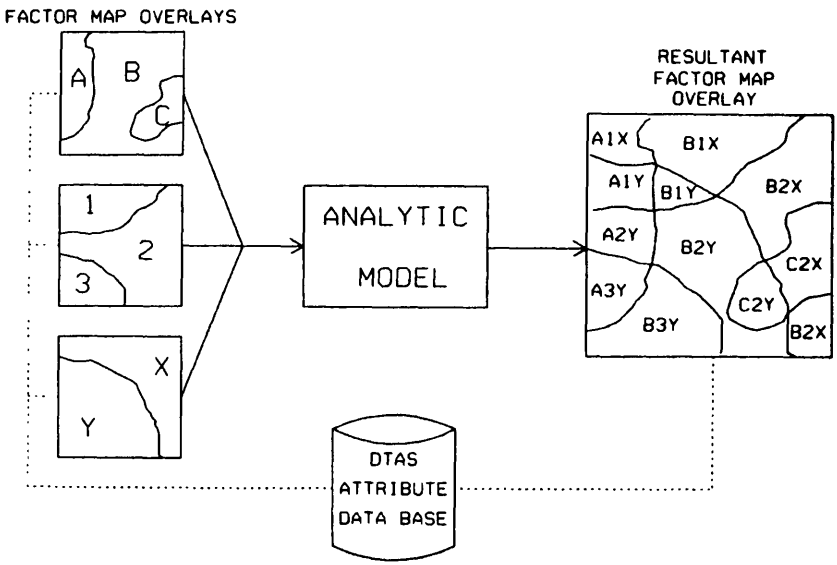

Figure 1. Computer-assisted terrain analysis schematic.

HARDWARE/SOFTWARE

Configuration

The DTAS operates on a PDP-11/70 minicomputer under the RSX-11M-PLUS operating system. The programming language is FORTRAN IV-PLUS. The graphics/data management capability is supplied by a turn-key interactive graphics design system. The graphics workstations have dual display screens, a digitizing table, a movable keyboard, a floating command menu, a multibutton cursor, and a built-in microprocessor.

Interaction

The DTAS is an integrated configuration of hardware and software which provides the means to compose original designs, encode existing drawings, modify designs, and store and retrieve designs under the interactive control of the user. The designs may be created either through direct user interaction at a workstation or through an applications program.

The data base management software is closely integrated within DTAS to provide the needed management of both graphic and associated nongraphic (attribute) data. The data base management software may be initiated through direct user interaction from a graphics workstation, through an alphanumeric terminal, or through an applications program.

Polygon Processor

A key feature of the DTAS is the capability to determine the spatial relationship between elements from two sets of polygons. Three boolean operations are supported: AND, OR, and NOT. The resultant set of polygons is stored in a design file and attribute values may be transferred from the original two sets to this resultant set in the form of read-only informational links. This capability is an integral component of the mobility models.

Data Base

Two data formats are currently used in the DTAS data base -- gridded data and graphic data. The gridded data is primarily used for intervisibility capabilities (Target Acquistion Model, Masked Area Plot, etc.) and the graphic data is used for the mobility capabilities (Cross-Country Movement, Concealment, etc.).

The current DTAS gridded data base consists of elevation and vegetation data and encompasses an area of over 4,000 square kilometers in Germany. It is designed for use with the Universal Transverse Mercator (UTM) coordinate system. The data was digitized using a grid mesh with a 125-meter spacing. The elevations were recorded at each grid lattice point. The most prominent vegetation type was recorded for each grid cell (125-meter by 125-meter square).

The current DTAS graphic data base consists of slope, soil, vegetation, water body, and urban area polygons and road, railroad, and waterway linear elements for the 1:50,000 Fulda, Germany map sheet, an area approximately 23 kilometers by 22 kilometers. This data was digitized on the DTAS from factor map overlays supplied by the Terrain Analysis Center at USAETL. Attribute values containing information about slope percentage, soil type, vegetation type, and other data were attached to these graphic elements. Attribute data may be retrieved and/or modified either through direct access or through an applications program.

EXISTING CAPABILITIES

The terrain analysis capabilities of the DTAS produce graphic products that fall generally into two major areas:

- o Intervisibility
- o Mobility.

The products may be displayed on the DTAS viewing screens or drawn to any scale on the DTAS plotter. They may stand alone or be used in compiling other products. For example, the combination of radar masking and cross-country movement produces a product that would be used by a terrain analyst in determining the least vulnerable avenue of approach.

Intervisibility

The intervisibility capabilities are used to determine areas that are visible, either optically or electronically, from a given site. These capabilities use the DTAS gridded data base and most have the user-selectable option of including vegetation heights in the analysis. The current DTAS capabilities in this area include:

- o Terrain Profile Model
- o Target Acquisition Model
- o Multiple Site Target Acquisition Model
- o Composite Target Acquisition Model
- o Masked Area Model
- o Perspective View Model
- o Path Loss/Line-of-Sight Model.

The Terrain Profile Model. This model displays the terrain profile along the great circle path between two user-selected points in a linear mode and in a 4/3-earth mode, showing a profile corrected for earth curvature and atmospheric refractivity.

The 4/3 earth plot is useful in checking optical or electronic visibility, i.e., in determining whether or not optical or electronic line-of-sight (LOS) exists between the profile endpoints.

When a profile is generated, the following options are available: the elevation of points along the profile may be interpolated from the four closest points in the data base or the nearest point may be used; the elevation of points along the profile (excluding the endpoints) may be augmented with average vegetation heights; and a table of elevations versus distance along the profile may be printed. The distance between the points along the profile, the antenna/observer heights at the profile endpoints, and the plot title are user selected.

The Target Acquisition Model. This model is used to determine the point at which an incoming target first becomes visible to an observer. One plot can be used to display the sighting contour for a number of altitudes for any observer sector from 0 to 360 degrees. This is done by retrieving the elevation (and associated vegetation heights if desired) of points emanating from the user-specified site in a pattern of equally spaced radial "spokes". Then a determination along each profile is made of the point that constitutes limiting line-of-sight and the distance from the site to this point. Once this is found, it is possible to determine the locations at which incoming targets are first detected for each user-requested altitude (either above sea level or above terrain). Finally the user-selected map projection is applied to these acquisition locations and a contour is drawn for each altitude.

Multiple Site Target Acquisition Model. Utilizing previously generated files from the Target Acquisition Model and a single, user-requested altitude, this model displays the acquisition contours for up to ten sites on one execution. These acquisition contours are drawn on separate levels in a design file, thus they may be displayed individually or in any combination.

Composite Target Acquisition Model. This model has the same input constraints as the Multiple Site Target Acquisition Model. The resultant plot, however, is a composite picture of all site acquisition contours for the given altitude. It is an outline plot, the logical sum of the individual acquisition contours, produced by eliminating any portion of a site's contour that falls within the bounds of another site's coverage. Thus it is possible to assess the cummulative detection capability of a number of sites operating in proximity to each other. Individual site markers are retained.

Masked Area Model. This model displays areas around a site in which a target at a user-specified height above ground level is shielded from the site (see Figure 2). The effects due to intervening vegetation is an option available to the user. All vegetation between the site and any point being analyzed is considered impenetrable.

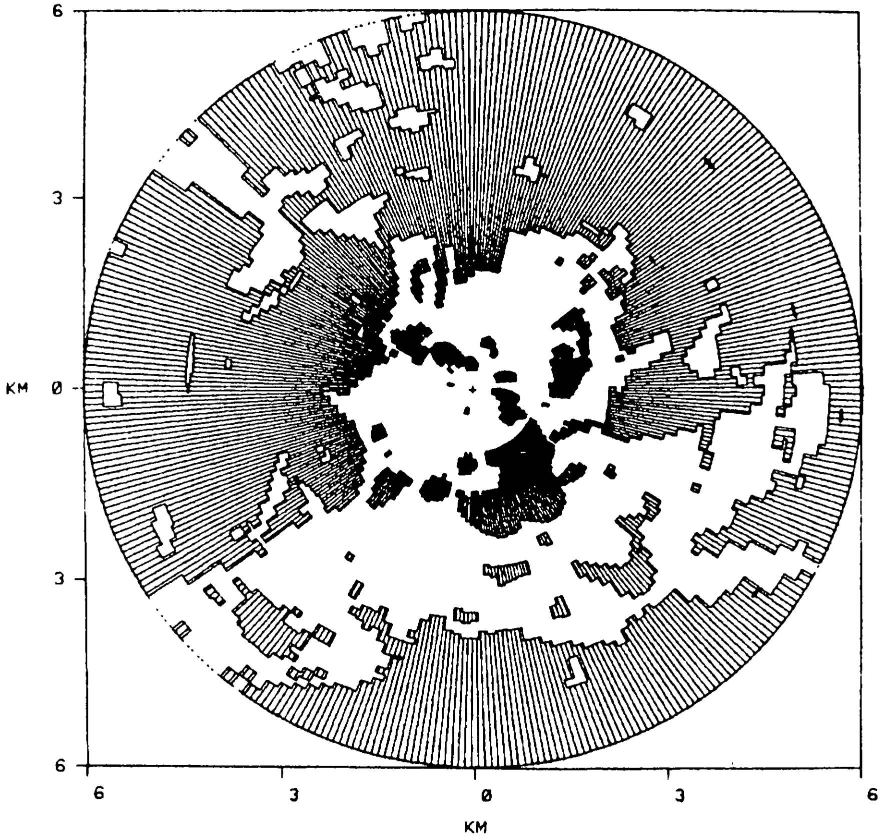

Figure 2. Masked Area Model Graphic Display.

Perspective View Model. This model provides the user a view of terrain in full perspective. The user has the flexibility to observe the terrain in any direction from any desired location and height above ground level or sea level. The terrain may be exaggerated vertically to aid in highlighting terrain features. Individual points on the surface may be flagged to aid in identifying significant features. Lines of equal distance from the observer may be superimposed on the surface to aid in the perception of distance. An overhead view of the area showing the observer's position, the limits of visibility, flagged feature spots, and range lines is displayed to aid in correlating the perspective view with map sheets of the area.

The perspective view consists of a grid of equally spaced lines following the changing elevations of the terrain. Those portions of lines which would be hidden by intervening terrain are removed. The resultant "fishnet" representation of the terrain (see Figure 3) provides the viewer with two important depth cues: the grid cells grow smaller as they become more distant, and the removal of hidden lines results in sharp edges outlining the tops of hills and mountains. The shapes of terrain features can also be discerned from the shading effect of the grid lines; areas which are almost parallel to the line-of-sight contain a greater density of grid lines and so appear darker than areas which are more perpendicular to the line-of-sight.

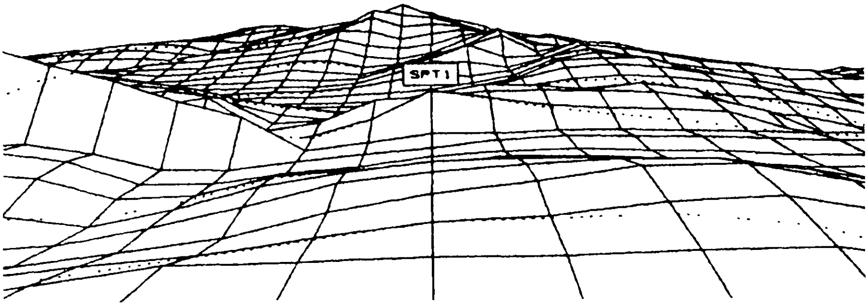

Figure 3. Perspective View Model Graphic Display.

Path Loss/Line-of-Sight Model. This model produces a display depicting path-loss-related calculations (power density, field strength, received signal, signal-to-noise ratio) or terrain shielding calculations relative to a specified site. The site may be located either inside or outside the coverage area.

Displays generated in the path-loss mode can be used to show base station transmitter coverage in terms of the signal produced at hypothetical receiver locations about the site. Base station receiver coverage with respect to hypothetical remote transmitter locations can also be depicted.

In the terrain shielding mode, displays can be used to define line-of-sight contours for radar and microwave installations, and optical line-of-sight for visual observation platforms.

Mobility

The mobility capabilities are used by terrain analysts to evaluate the potential effects of terrain upon friendly and enemy operations. The current DTAS capabilities in this area include:

- Local Relief Model
- Slope Model
- Cross-Country Movement Model
- Cover Model
- Concealment Model
- Key Terrain Model
- River Crossing Model.

Local Relief Model. This model displays a user-selected area divided into five-kilometer squares, with the minumum and maximum elevations and the difference between these two values depicted for each square. The difference is the local relief value and is used to roughly categorize an area as plains, hills, or mountains.

Slope Model. This model determines the percent-of-slope for every gridded elevation data point in a given area and displays the areas that are within a user-specified range of slope percentages. This product is an important ingredient in many other products (e.g., cross-country movement, cover, etc.).

Cross-Country Movement Model. This model displays off-road speed capabilities based on the characteristics of a user-selected vehicle and the slope, vegetation, and soil that occur in a given area. Prevailing movement conditions are categorized as GO, SLOW-GO, and NO-GO.

This model is the most comprehensive of the all the models in terms of complexity and volume of graphic data that must be processed.

Slope is evaluated based on the maximum climb capabilities of the user-specified vehicle. Vegetation (stem spacing and diameter) is evaluated based on vehicle dimensions and override capabilities. Soil is evaluated in terms of the rating cone index for each soil type and the vehicle cone index.

The slope, vegetation, and soil polygons are merged by the system through a series of successive boolean AND operations to produce a final Cross-Country Movement graphic (see Figure 4). In addition, the resultant polygons retain the original attributes linked to them in the attribute data base.

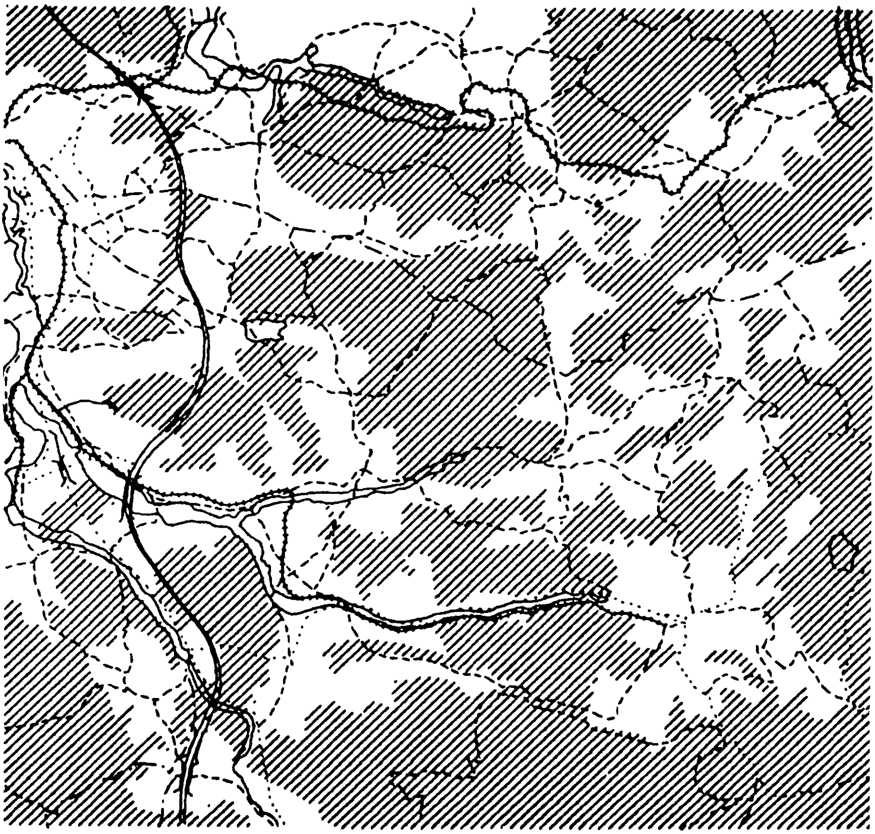

Figure 4. Cross-Country Movement Model Graphic Display of NO-GO areas and transportation network.

Cover Model. This model determines the amount of protection from flat-trajectory fire provided by vegetation, slope, and urban areas. The Cover display delineates areas that afford good, fair, or poor protection.

Concealment Model. This model determines the percentage of aerial concealment provided to a vehicle, man, or unit on the ground, based on the vegetation in the area of concern. The Concealment display delineates areas that provide concealment, graduated from the best areas (0-25% chance of being detected) through the poorest (75-100% chance of being detected).

Key Terrain Model. This model combines elevation data from the gridded data base with vegetation and slope data from the graphic data base to synthesize a display of suitable high ground areas within a user-specified region. Requirements for acceptable high ground are accessibility (i.e., slope <30%), reasonable concealment (i.e., canopy closure >50%), and prominent elevation relative to the surrounding area. The model offers a choice of summer or winter concealment conditions.

River Crossing Model. This model compares the characteristics of a user-chosen equipment against the features of each waterway segment to determine its potential as a crossing site. Some of the features used in the analysis are bank height and slope, bottom material, and water depth.

All of the above models have been developed and are resident on the DTAS. Exhaustive testing of each model will commence as format-compatible terrain data bases are loaded into the system.

CURRENT DEVELOPMENTS

Prototype DMA Data Bases

A major consideration in the development of DTAS is the data base required to feed such a system. To create the type of products mentioned thus far is relatively simple for a small geographic area or with simulated data. To be of value to the field Army however, the system must be capable of accepting large volumes of real data, data that is potentially obtainable for worldwide coverage. It is desirable to define a single data base capable of satisfying all digital terrain data requirements.

To this end, the Defense Mapping Agency has created two prototype data bases. Each prototype covers the same area of Fort Lewis and the Yakima Firing Center in the state of Washington. One prototype is in a gridded format and the other exists in a vector format. In the near future, these two prototypes will be evaluated using DTAS to reformat the data and to generate products. The output products will then be compared to manually produced products and ground truth. Input resolution will be traded-off against required quality.

New Models

Additional analytical capabilities currently being added to DTAS include:

- Air Avenues of Approach Model
- Drop Zone/Helicopter Landing Zone Model
- Barrier/Denial Model
- Infiltration Routes Identification Model
- Lines-of-Communication Model.

Air Avenues of Approach Model. This model will produce a graphic display of areas around radar sites in which an aircraft at a specified altitude above ground level cannot be detected. This display will be supplemented with areas from the Concealment Model that exhibit the least chance of being detected by ground forces. This can be a season-dependent input, either summer or winter. In addition, urban areas, transportation, and drainage will be shown as navigational aids. Obstacle data above a user-selected height may also be displayed.

Drop Zone/Helicopter Landing Zone Model. This model will produce a graphic display of areas suitable for drop zones and helicopter landing zones. The user will be able to indicate the minimum dimensions or the model will use default dimension values to select the areas. The display will be supplemented with areas from the Cover and Concealment Models that exhibit the least chance of being detected by enemy forces and areas from the Cross-Country Movement Model which indicate good off-road mobility. In addition, urban areas, drainage, obstacles, and transporation will be displayed at the user's option.

Barrier/Denial Model. This model will produce a graphic display of areas determined to be NO-GO areas and features whose attributes make them obstacles (e.g., wide, deep rivers and urban areas). This display will use the Cross-Country Movement Model to determine NO-GO areas. In addition, the user will be able to display data from the transportation and drainage overlays as well as from the Path Loss/Line-of-Sight Model at his option. Using these combined displays, the terrain analyst will be able to select and add various obstacles for display and plotting.

Infiltration Routes Identification Model. This model will produce a graphic display of areas not covered by enemy surveillance sites. This display will be supplemented with areas from the Cross-Country Movement Model that will allow off-road trafficability. Areas providing concealment from aerial observation will be shown along with areas providing cover from ground fire. This information will come from the Concealment Model and Cover Model, respectively. In addition, the user will be able to display data from the transportation, drainage, and/or obstacle overlays at his option.

Lines-of-Communication Model. This model will assist planners in conducting route analysis. Based on the size, weight, and speed capabilities of a unit's vehicles and the road networks contained in the data base, field commanders and their staffs can use this model to quickly analyze primary and alternate routes. This capability is especially critical to the concept of the "Active Defense", where a commander must consider numerous contingencies to redeploy his forces on a rapidly changing battlefield as well as to evaluate the enemies reinforcement capabilities.

CONCLUSION

Results thus far have proven very promising. The feasibility of providing the terrain analyst a usable, automated tool has been demonstrated. The next step is to take the capabilites of DTAS, demonstrated in a laboratory environment, and develop them into a fieldable Digital Topographic Support System. This includes the definition of the all important digital topographic data base, integration of militarized computer hardware that can withstand the rigors of a field environment, and the definition of interface requirements with other military systems. In addition, the models will be further analyzed and refined as necessary to insure they are tailored to the users' specific needs. These efforts have been initiated and are ongoing projects at the U.S. Army Engineer Topographic Laboratories.

THE APPLICATION OF STRUCTURED SYSTEMS ANALYSIS TO THE DEVELOPMENT OF AN AUTOMATED MAPPING SYSTEM

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ABSTRACT

In many cases, automated mapping systems seem to have been designed and acquired without due regard for their intended use. A structured, systematic approach, however, increases the chances of successfully implementing such a system. This paper focuses on how the Mapping Services Branch and the Computer Systems Development Branch of the Tennessee Valley Authority (TVA) used such a structured approach in conducting the first phase of system acquisition (i.e., a feasibility study).

The use of a commercially available methodology enabled the project team to proceed with the feasibility study in a logical order, starting with the project scope, continuing through problem identification and general system requirements, and ending with a financial analysis of the proposed system. We believe this approach has greatly improved TVA's chances of success in designing, acquiring, and implementing a system for digital photogrammetric-based mapping, map compilation, and revision of 1:24,000 and 1:100,000 national map series topographic quadrangles, cadastral maps, and special-purpose mapping to support such TVA programs as recreation, power, and wind energy.

INTRODUCTION

Since March 1980, the Tennessee Valley Authority* has been involved in the procurement of an automated mapping system to lower the cost of maps produced both for TVA and as part of the National Mapping Program.** To date, a feasibility study, a System Design Manual, and a request for proposals for such a system have been produced. The feasibility study and System Design Manual were prepared using a

*TVA is used in this paper with specific reference to the activities of the Mapping Services Branch and the Computer Systems Development Branch, both in the Division of Natural Resource Operations, Office of Natural Resources.

**Under an agreement with the U.S. Geological Survey, TVA has the responsibility for mapping and maintaining the 775 seven-and-one-half minute quadrangles that lie within the 40,000-square-mile Tennessee Valley. In 1980, the USGS agreed to let TVA produce the 71 metric-base 1:100,000 quadrangles that cover the TVA power service area, an area about twice the size of the watershed. TVA additionally produces and maintains cadastral maps for all of its property holdings, navigation, as well as recreation, and other special-purpose maps to support various TVA programs.

structured system analysis and design methodology called "PRIDE," which stands for "PRofitable Information By DEsign through Phased Planning and Control."* The use of this systems methodology has been required by agency policy for all ADP procurements in TVA since 1976.

Our initial systems development effort (which resulted in a feasibility study) facilitated the subsequent writing of the Request for Proposals. This paper will discuss the activities undertaken using PRIDE to produce a feasibility study for an automated mapping system.

PROJECT SCOPE

The first step we took in the feasibility study was to define the project scope. In order to do this, we looked at what administrative units would be involved and what functions in these units would be affected by the introduction of an automated mapping system.

Our first project scope definition included the Cartographic Section and the Photogrammetry and Remote Sensing Section of the Mapping Services Branch. Cartographic applications to be addressed were the production of 7-1/2 minute topographic quadrangles; metric base 1:100,000 topographic quadrangles, cadastral maps, records, and measurements; and special-purpose maps and graphics. Those photogrammetric applications to be addressed were 7-1/2 minute and large-scale topographic manuscript production, special-purpose mapping and profiles, cross sections, and volumetric computations.

During the feasibility study, the project scope was redefined to include, in the Photogrammetry and Remote Sensing Section, only Valley Topographic (National Mapping Program) Mapping and special-purpose mapping. The Cartographic Section scope remained the same, and a third area, "Management," was added. This last application is intended to be a relatively small part of the Automated Mapping System; it will include such applications as system utilization and map production tracking and reporting.

The project scope was a critical part of the feasibility study; once the study was approved by branch, division, and office management, the project scope was fixed. This has already helped in turning aside requests and ideas for other applications to be put on the system until the applications outlined in the scope have been implemented (i.e., the project scope has been used to avoid being sidetracked from our original purpose).

*"PRIDE" is a proprietary product and registered trademark of M. Bryce & Associates, Inc., Cincinnati, OH 45215.

DOCUMENTATION

The next step in our feasibility study was to document the existing administrative system, workflow, and information needs. (Information needs are the "pieces" or types of information needed for a procedure in the workflow to take place.)

We first assembled the existing organization charts for the Mapping Services Branch. Using the project scope, we then decided which people in which functional areas we wanted to interview. The interviews, conducted with about 15 percent of the branch personnel, clarified the administrative organization and provided a basis for documenting the workflow.

The workflow was best divided into four product-related areas: cadastral maps, 7-1/2 minute quadrangles, 1:100,000 quadrangles and special-purpose maps. Charts were then constructed showing the present flow of each type of map production, and, to check their accuracy, they were reviewed with the people working in those specific areas. The workflow diagrams, in conjunction with our interview notes, enabled us to construct a new set of charts showing the information needs for each procedure defined in the workflows. These charts show each procedure on a separate line, and for each procedure they show the source of the information needed, the actual information needed, the administrative unit requiring the information, the data output as a result of this procedure, and the destination of the data. The data output as a result of one procedure most often becomes the information needed by a subsequent procedure.

Using the information needs charts, we identified those procedures (taking into consideration their information requirements) that were likely candidates for automation. With these procedures identified, we then used our interview notes and workflow diagrams to see which specific workflow problems could be alleviated.

PROBLEM IDENTIFICATION

The activities described above enabled us to identify the following problems that were amenable to automated solutions:

1. Labor intensiveness of the manual system, which has been responsible for the increasing cost of map products.

2. Unfilled requests for new maps or map updates due to production limitations.

3. Lack of flexibility in production; usually only one set of (master) negatives are available for a map. This especially affects special-purpose mapping, which uses common map bases to create many specialized products.

4. Maintenance of redundant data (multiple sets of

map negatives) for maps produced at different scales--especially for special-purpose maps.

5. Large amount of reprographics (shop) work required to produce derived maps (for example, 1:100,000 quads from 1:24,000 quads and nuclear power plant radius maps from 1:100,000 quads).

SYSTEM REQUIREMENTS

Once we knew what the problems were that we had to solve, it became possible for us to set out both general and specific requirements for an automated mapping system.

The general requirements are that the system must be installed (implemented) without affecting current production and that it be compatible insofar as possible with TVA's Geographic Information System and the USGS's digital cartographic program. The system must be able to produce map revisions that meet current accuracy standards more economically than through manual means, and it must be flexible and expandable to incorporate additional applications. Furthermore, it must be able to interface with TVA's central computer.

Specific requirements were then outlined for each type of map production. For cadastral mapping, the elimination of much redrafting that now takes place for successive versions is essential to generate cost savings. Because special-purpose maps are derived from existing map bases, the system must support the selective display, editing, and plotting of data. Data manipulation, such as scale changes, is critical to reducing the presently large amount of shop work on such maps, which in turn will allow a faster map production turnaround time. For 7-1/2 minute and 1:100,000 quadrangles, the system must support the conversion of detailed map data from graphic into digital form, and the interactive editing and plotting of this data while maintaining the accuracy standards of the national map series. Significant cost savings for these maps depend upon high-quality plotting of line work that will eliminate much of the lengthy scribing process. The availability of this data in digital form will additionally provide base map data to support compilation of most of the derived maps we produce and analysis for natural resource planning, most of which will be performed by TVA's Geographic Information System.

These requirements in particular provided a framework that was later helpful in writing a Request for Proposals.

FINANCIAL ANALYSIS

At this point in our feasibility study, we knew what the problems of the system were and how we intended to solve them. This was fine, except for the fact that we had not yet asked ourselves if TVA would ultimately benefit from the project. Clearly, if the benefits (including dollar savings and new capabilities) did not outweigh the costs, the project could not be justified. Our next job, then, was to cost-justify the proposed system. We consulted a TVA economist to be sure that we used a sound method of cost justification. Two major ways of analyzing the costs and benefits of a project were suggested: an economic analysis and a financial analysis. A financial analysis takes inflation into account during the system's useful life,* whereas an economic analysis does not. We were advised that with a labor-saving application such as ours it would be to our advantage to do a financial analysis, since the cost of manual labor will rise faster than will the system's life (10-year) cost of paying for and operating a computer system designed to replace much of the manual labor.

To proceed with a financial analysis, it was necessary to arrive at figures representing initial costs for the system, annual operating costs, benefits to cartographic production, and spinoff benefits to others.

Initial Costs

Since the vendor who would supply our system was unknown, we were able to arrive only at an approximate system cost. This was done by obtaining the prices for all hardware and software modules that would be needed to support our application from a vendor likely to be a strong contender for our contract. To this system cost were added the estimated costs for a high-precision photohead plotter (to be acquired two years after the initial system purchase) and for systems development (estimated by our Computer Systems Development Branch).

Annual Costs

Annual costs consisted of interest and amortization, additional interest and amortization after purchase of the photohead plotter, data base loading, maintenance, and systems support. Interest and amortization for the initial system and for the photohead plotter were taken from standard tables and represent what the borrowed money will actually cost TVA on a yearly basis. Data base loading was based upon the number of workstations and shifts available. With our two initial workstations, we felt we could assign two full shifts to one workstation and one-half shift to the other workstation for data base loading. The related cost was based on an average cost for a workstation operator. This process has been given a high priority, because data must be loaded into the system or be available to the system in digital form before the system can support production. Annual maintenance costs were based on roughly 10 percent of the system purchase price. This seems to be the figure used by most vendors. The need for internal systems support was an estimate based only on projected need.

*The useful life of a system can usually be extended by making modifications to the system.

Benefits to Cartographic Production

The benefits to Mapping Services Branch cartographic production were calculated for the initial system only and for the system with a high-precision photohead plotter. These calculations showed a significant increase in expected savings due to purchase of this plotter after the first two years of operation.

To calculate these benefits, we first had to collect data on the current costs of producing maps manually. Through estimates given by our production people and information extracted from production and cost records, we were able to arrive at the approximate number of hours needed to produce each type of map considered in the study. For the two topographic quadrangle series, however, the number of hours needed for each step in the production of these maps was recorded because of their more complex production flows.

The average wage rate for the people producing these maps was added to shop costs (as a percentage of the total), overhead costs, and benefits, so that the figure would represent TVA's true cost. This wage rate was then multiplied by the number of hours needed for each map (or map production step) to yield a current cost figure for each type of map we produce.

The next activity we undertook was to determine the probable production savings. On the basis of our knowledge of cartography and automated mapping system capabilities, we talked with the same people we had interviewed earlier for time estimates. After having briefly explained some of the capabilities of automated systems, we together arrived at what we felt would be a reasonable figure for either the percentage of time or the number of hours that would be saved using automated methods. These estimated savings were then converted to dollars and subtracted from the manual labor costs to yield automated map production costs.

For all types of mapping except cadastral, we generated two sets of figures for automated production costs: one with the initial configuration (containing only a pen plotter) and one with the high-accuracy photohead plotter. This was done because most of the savings for the topographic map series are based on the reduction of the labor-intensive map finishing process (especially scribing), which can be accomplished only when the photohead plotter is installed. Some extra savings are expected for special-purpose maps because of a reduction in shop work. Significant savings, however, will be possible with just the pen plotter in cadastral and special-purpose mapping because of less stringent production specifications. Additionally, because cadastral maps are produced only in black and white on a single layer of drafting film, there is no need for color proofs or separations.

It should be noted that the calculation of these benefits was based upon the continuation of the existing workload.

As long as the workload remains constant or increases, the benefits will remain valid.

Benefits to Others

Benefits to others represent the value--inside and outside TVA--of the digital cartographic data that will be part of the system. While these benefits are more difficult to document than the benefits to the Mapping Services Branch, they are every bit as real. In most cases, the values of these benefits were determined jointly by us and the people responsible for the areas involved. We feel that our benefit estimates are on the conservative side; actual benefits may turn out to be much greater.

Analysis

After having calculated the initial costs, annual operating costs, and both sets of benefits, we performed our financial analysis to arrive at a benefit/cost ratio for the project. The detailed methodology of this analysis is beyond the scope of this paper; however, it should be noted that inflation and the cost of money to TVA were included as factors affecting the costs and benefits of the proposed system.

PRIDE allows the systems analyst an opportunity to refine the cost/benefit analysis performed in the feasibility study. This analysis is also required in the next phase, the System Design.* Our financial evaluation in the feasibility study yielded benefit-to-cost ratios of 2.2 for internal cartographic production and 2.6 for all users. When we informally repeated the analysis with better and more up-to-date data as part of our Phase II (System Design Manual), we arrived at figures of 2.0 for internal production and 2.4 for all users. One should understand that a financial analysis is a continual process of refinement; the analysis can only be as accurate as the data on which it is based. In PRIDE, the analysis is used as a basis for management approval, modification, or cancellation of a project. If the project is approved, as it was in our case, the true test comes after implementation, during the system audit. Then we will be able to assess the accuracy of our predictions.

SUMMARY

PRIDE, a structured systems methodology has enabled the personnel involved in TVA's Automated Mapping System to see where they are going before the system is purchased. We have defined our five application systems and their major steps, and we know how each system's data will be shared--we know what we have to do to make the system work. By defining the project scope, documenting the existing system, identifying the existing problems, setting out system requirements, and analyzing the costs and benefits

*In the PRIDE methodology, the System Design is the second of nine phases.

of the system, we at TVA have gone into this project with our eyes open. To date, we have received very few surprises and expect fewer than usual during system implementation because of our use of structured systems analysis.

ACKNOWLEDGEMENT

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RASTER DATA ACQUISITION AND PROCESSING

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BIOGRAPHICAL SKETCH

Richard F. Theis received a Bachelor of Science degree in geography from the University of Maryland. He is presently employed by the U.S. Geological Survey, National Mapping Division. His responsibilities include research and development of digital cartographic systems in support of the National Mapping Program.

ABSTRACT

The National Mapping Division of the U.S. Geological Survey has the responsibility for building and maintaining a Digital Cartographic Data Base (DCDB) to support the National Mapping Program. A major task which must be accomplished to fulfill this mission is the conversion of data contained in over 40,000 published 1:24,000-scale topographic maps to digital form for entry into the DCDB. The raster data acquisition and processing system being developed for this task is comprised of three components: (1) raster scanning and editing on a Scitex Response 250 System; (2) raster-to-vector conversion on a DEC minicomputer; and (3) vector editing and attribute tagging on an Intergraph Interactive Graphics Design System. The system, still in the early stages of development, has established the feasibility of raster scanning and processing as a viable method of data capture.

INTRODUCTION

The National Mapping Division (NMD) of the U.S. Geological Survey (USGS) is responsible for fulfilling the objectives of the National Mapping Program. One primary objective of the program is to collect and disseminate selected topographic information in digital form. The vast majority of this digital topographic information will come from more than 40,000 published 1:24,000-scale quadrangle sheets that are archived on stable base color separation films.

The current procedure used to collect data from archival materials is by manually digitizing features and attaching attributes to the digitized features; editing the line and attribute data; and finally, storing the data in the Division's Digital Cartographic Data Base (DCDB). The

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DCDB is the digital counterpart of the film archive. Manual digitization works sufficiently well for the collection of most map features with the notable exception of contours. Because manual digitizing is a slow, labor-intensive procedure, it is not feasible to be used as the primary method of capturing the contour data from over 40,000 quadrangles in a timely, cost-efficient manner. An automatic means of digitizing data was called for. To fill this need the NMD acquired a Scitex Response 250 System with raster data scanning, editing, and plotting capability.

The Scitex system components include a scanner, a color design console, and a laser plotter, each with a HP 21MX E host processor. The scanner and design console are used for data capture. The scanner is a drum-type raster scanner capable of digitizing sheets up to 36 inches by 36 inches in size at resolutions between 4 and 47 points per millimeter (.25 and .02 millimeters) at a speed of 130 revolutions per minute. The design console, used to interactively edit the raster data, is composed of a color CRT, a digitizing tablet with pen cursor, and a function keyboard. The design console also carries an extensive set of system batch-edit commands.

While the Scitex has solved the problem of time and cost-efficient contour data collection, it has added some additional problems--the foremost being the need to convert the Scitex raster-formatted data to the vector format required by current DCDB processing software. To overcome this problem, NMD obtained a raster-to-vector (R/V) processing program from Dr. A. R. Boyle of the University of Saskatchewan, Canada. This program underwent considerable modification although the basic algorithm was unchanged. In addition, pre-and post-processing routines were written to form a complete R/V processing system. This software is currently operational on PDP-11/70 and PDP-11/60 minicomputers.

The last phase of the R/V processing software builds an Intergraph design file. The Intergraph is a PDP-11/70 based interactive graphics design system. On this system the contour data, in vector format, undergo attribute tagging and final editing in preparation for input to the DCDB processing system.

Three phases of raster data acquisition and processing are discussed in the following text: raster scanning and editing, R/V processing, and vector editing and attribute tagging (see figure 1). All phases are in operation at the National Mapping Division but are still under development. The Unionville, New York, New Jersey, quadrangle contour feature set is used for reference where explanation of a procedure is enhanced by using an example.

RASTER SCANNING AND EDITING

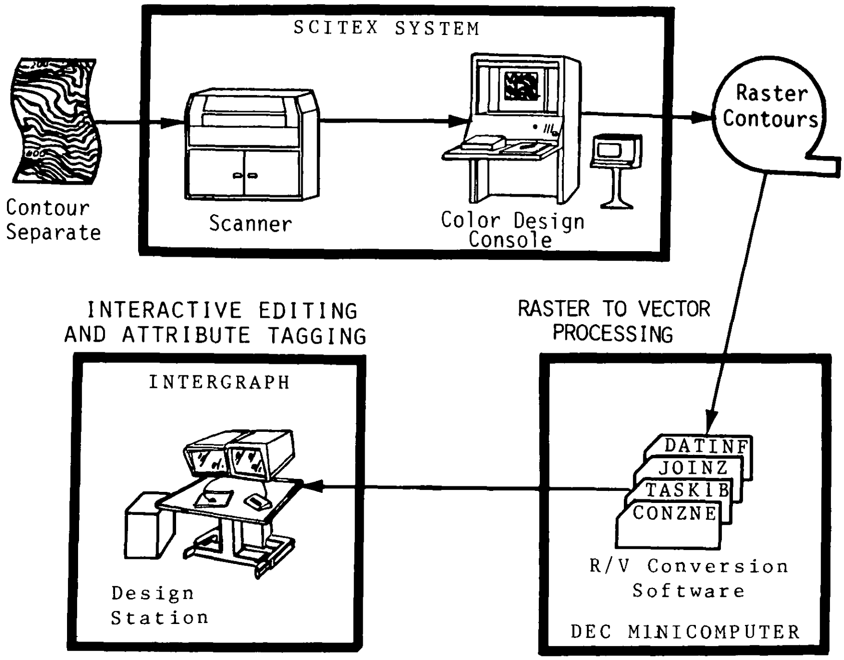

Figure 1. Raster Data Acquisition and Processing

RASTER SCANNING AND EDITING

Scanning

The scanning operation, aside from initial operator setup, is fully automatic. The scan setup procedure begins by securing the film positive source over a white background to the scanning drum. The operator then executes the SCAN command. From this point the SCAN program controls all operator activity. SCAN directs the operator to perform a series of scan initialization procedures, including color calibration and identification of the source area to be scanned. SCAN also prompts the operator to enter scanning specifications such as film thickness and scanning resolution. Upon completion of these initialization procedures, scanning begins. As the scanner drum rotates, the electro-optical scanning head digitizes a column of pixels (picture elements), commonly referred to as a "scan line". The scan head interprets the qualities of light reflected from each pixel and then assigns the pixel the closest calibrated color code. Although the scanner can recognize up to 12 colors; when scanning film positives only two colors are calibrated during scan initialization --black for line work and white for background. The color code assigned to each pixel is stored in digital form on a magnetic disk. After each revolution of the drum, the scan head steps across the drum to digitize the next scan line. When the head has moved across the entire predefined area of the source film, scanning stops and the feature data are then ready for display and edit on the Color Design Console.

The Unionville contour sheet, which measures 17 inches wide by 23 inches high, was scanned at a resolution of 20 points per millimeter (.002 inches). It took approximately 1 hour and 20 minutes to scan. In digital form the sheet measured 9,515 pixels (scan lines) wide by 12,359 pixels high (including 1 inch overedge). The size of each pixel was .002 inches (.05 mm) square.

Editing

The ultimate goal of the editing procedure is to produce a clean contour data set in which only the contour lines and registration ticks reside. All contour lines must be separate, continuous, and one pixel in width . The first task is for the operator to separate distinct features in the file by assigning unique colors to them. Using the design console and the PAINT command, the operator interactively steps through the file and places a dot of color on elevation labels, index contours, registration ticks, and any spots of dirt or noise picked up by scanning. The PAINT command will automatically change the color of a feature to that of the dot placed upon it. Elevation labels and spots of dirt are changed to the background color, thereby deleting them from the file. Index contours and corner ticks are assigned the same color. This procedure results in a three-color file which includes the background color, the index contour and registration tick color, and the intermediate contour color. This feature separation procedure on the Unionville contour set was completed in 4 hours.

Before editing can begin on individual contour lines, the lines must be thinned to a one-pixel width centerline. This operation is performed automatically on all elements in the file by the MIDLINE command. MIDLINE retains the original width definition of the lines and produces in the same file one-pixel width centerlines in a contrasting color. This allows the operator to edit the contour centerlines utilizing the original line width representation as a guide. MIDLINE processed the Unionville data in 3 hours.

After MIDLINE, the FINDEP (find end point) command is initiated. FINDEP is used to locate breaks and spurs in contour centerlines, miscolored contours, and unwanted line symbolization such as depression ticks and dashed lines. The command automatically searches the file for end points of lines. When one is found, it is displayed on the console CRT and control is returned to the operator. The operator can then interactively correct any problem with the displayed line. Breaks in contours are closed, spurs and depression ticks are deleted, and miscolored contours are corrected. When editing of the located line has been completed, the operator then returns control to FINDEP which proceeds to search for the next end point. FINDEP continues executing until all end points in the file have been visited. This process was completed in 4 hours on the Unionville contours.

The next step in the editing procedure involves separating those contours which coalesce. The NODE command is used for this operation. It functions in the same manner as the FINDEP command except that it locates points where lines intersect. As each intersection is found, the operator interactively separates the lines. During this operation lines are never shifted more than one pixel width from their original location. The NODE operation on the Unionville contours was completed in 2 hours.

During the interactive editing procedures on the center-line contours, the operator draws lines in the file either to close gaps or realign contours. The lines input in the drawing process are not of uniform one-pixel width; thick portions of lines are produced where the operator paused while drawing or where new lines meet existing lines. A second automatic thinning operation (MIDLINE) is performed on the data set to remove these thick portions. This second thinning operation on the Unionville contour set took 1 hour.

At this stage the contours are separate, continuous, one-pixel width lines which are ready for R/V processing. The contour file is written to magnetic tape which is then transported to the PDP computer for processing.

RASTER-TO-VECTOR PROCESSING

Scitex raster data designated for entry into the DCDB must first be vectorized so that individual features can be identified and assigned appropriate attribute codes (e.g. elevation). The R/V processing software used to perform this function consists of four programs: CONZNE, TASK1B, JOINZ, and DATINF. CONZNE converts run-length encoded data of the Scitex tape to bit-serial form, and then segments the bit-serial data into 512 by 512 pixel (bit) blocks called zones. TASK1B vectorizes the data set one zone at a time. JOINZ joins together lines which cross zone boundaries to produce a continuous data set. DATINF filters the vector data set and builds an Intergraph design file. In short, the R/V processing software reads a Scitex raster data tape, converts the data to vector form, and produces an Intergraph design file in which the data are ready for interactive editing and tagging. With the exception of TASK1B, all software is coded in FORTRAN. Because TASK1B performs bit processing, it is coded in Assembler language. The functions of each R/V processing software module are described in greater detail in the following text.

CONZNE

The role CONZNE serves in the R/V software is to prepare data which has been scanned on the Scitex for TASK1B processing. This preparation is accomplished through the performance of two tasks. The first task is that of converting the Scitex run-length encoded data to bit serial form. Run-length encoded data are data in which each scan line is defined by a varying number of 16-bit, run-length words. Each run-length word defines a number of consecutive pixels of like color in a scan line. Run-length words carry two values: one specifies the color code; and the other denotes the number of consecutive pixels which exhibit that color. Run-length encoding is an efficient and compact form in which to store multi-color raster data sets. Bit-serial format, on the other hand, represents scan lines as a fixed-length series of bits. Each bit represents a pixel in the raster data set. Only two colors can be stored in this format: an active color represented by set bits (1); and a back-ground color represented by clear bits (0). Although bit-serial format represents only one color and requires significantly more storage than the run-length format, it is much more conducive to the bit processing performed in TASK1B.

The second task performed by CONZNE is that of segmenting the bit-serial raster data into 512 by 512 bit blocks called zones. Zoning serves to break down the large data set into manageable units. A zone is the maximum unit of data which the vectorization routine, TASK1B, will process at one time.

One 512 by 512 bit zone requires 16,384 words of memory to store. This figure amounts to one half of the maximum task image size supported on the PDP 11/70 and 11/60 mini-computers. The Unionville contour set was segmented into 475 zones--19 zones wide by 25 zones high. At a scan resolution of 20 points per millimeter (.05 mm), each zone covered approximately one inch square on the map. Even though the zone is a small segment of the entire data set, it is in itself a large volume of data. A column of zones, made up of 512 scan lines, is called a band. Zones are stored on disk in files according to the band in which they reside.

Because the Unionville data set was comprised of three colors representing index contours, intermediate contours, and background, the data set was processed through the R/V software twice--once to process the index contours, and again to process the intermediate contours. CONZNE processed the Unionville index contours in 1 hour 15 minutes and the intermediate contours in 1 hour 19 minutes.

TASK1B

TASK1B is the key program in the R/V processing software. It is this routine which actually performs the R/V conversion. Conversion is performed on one zone at a time. TASK1B utilizes three important components in the R/V process: a decision template; a node table; and a next position table. The decision template, which is defined in the program code, can be described as a 3- by 3-square matrix of which the eight peripheral squares have assigned to them the values of 1, 2, 4, 8, 16, 32, 64, and 128. The central square has a value of zero. The sum of any combination of template values will produce a unique number between 0 and 255. These numbers directly correlate with locations containing decision information in the node and next position tables. The node table is a node/intermediate point determination table which takes the form of a 256-bit array in the program. Each bit in the array holds a predetermined decision as to whether a bit (pixel) in the raster data set is a node or an intermediate point. A set bit (1) designates a node; a clear bit (0) designates an intermediate point. The next position table is also an array within the program and is 256 16-bit words in size. Each word in the array holds a predetermined address offset value which points to an address in the zone data to which the decision template is to be placed next.

Utilizing the decision template, TASK1B can examine a pixel (bit) of the zone array in relationship to its immediate eight possible neighbor pixels and subsequently make two decisions. The first decision, determined by the node table, is whether the pixel under examination (pixel of interest) is a node or an intermediate point. The second decision, made by the next position table, is the address of the next pixel in the zone array to be examined. Vectorization of a zone proceeds in the following manner. The decision template is moved sequentially through the zone array until a set bit (pixel) is encountered, indicating the presence of a line. This set bit becomes the pixel of interest, and the decision template is positioned directly over it . The pixel of interest always falls within the zero square of the decision template. Once placed, the eight peripheral squares of the template are examined. Values of template squares containing set bits are added together. The sum of these values becomes the pointer value which points to locations , containing decisions, in the node and next position tables. The node table is referenced first. If the node table determines the pixel of interest is a node, an end point of a line has been found. Whenever a node is encountered, a vector-line record is either opened or closed, depending upon whether the node is the first point of a line or the last point. A line record is opened if one does not already exist when a node is found. In this case, the zone coordinates of the node (current pixel of interest) are computed and written to the new line record. The line record is closed upon encountering a second node immediately after the coordinates of the node have been written to it. Whenever an intermediate point is identified, its zone coordinates are simply appended to the current line record.

After the pixel of interest has been identified as node or intermediate and its coordinates added to the line record, the next position table is referenced. The decision template is moved to the location of the adjacent set bit indicated by the table. The bit at this new location becomes the next pixel of interest, and the evaluation procedure begins again. The template continues following the line in this fashion, recording its coordinates to the line record as it goes, until the end node is encountered. All lines in all zones are vectorized in this manner. Completed line records are stored by zone in files on a disk according to the band in which they reside.

TASK1B processed the Unionville index contours in 14 minutes and the intermediate contours in 21 minutes.

JOINZ

After TASK1B processing, the vectorized data set remains segmented into zones. A single line several inches in length on the original scan manuscript would exhibit the following characteristics in the data set produced by TASK1B: the line will cross several zones, resulting in a line divided into several segments (records) with each segment being stored in a different local zone coordinate system; adjacent segments of the line may flow in opposite directions; and common endpoints of adjacent segments will not be the same but will fall at least one pixel apart.

What needs to be done to this line, as well as all other lines in the data set, is to join all of its component segments together to produce a single, continuous line which is stored in one coordinate system. In other words, the zoned data set must be unsegmented and restored to the point where it exhibits in digital form the same characteristics of its prescanned graphic counterpart. This operation is performed by the JOINZ program.

JOINZ utilizes endpoint matching to join together segments of a line. Before matching is begun, all line segment coordinates in the entire data set are converted from local zone (0 to 511) to absolute sheet coordinates (0 to 32,767). When this conversion is completed, JOINZ initiates a sequential search through the zones for the next unprocessed line segment. As line segments are processed, they are flagged as such so that they will be skipped by the sequential search. Upon initiation of the sequential search, no line segments have been processed and it stops at the first line segment of zone one. When an unprocessed line segment is found, a joined-line record is opened and the coordinates of the segment are written to it. The last coordinate written to the joined-line record is retained as the search coordinate. The search coordinate is then examined to determine the candidate zones in which a possible match endpoint might be found. The number of candidate search zones can range from one to four depending upon the position of the search coordinate within the zone and the position of the current zone within the data set. Endpoint coordinates of all line segments within the candidate zones are compared to the search coordinate. If an endpoint falls within four pixels of the search coordinate, then a match is found. The matched line segment coordinates are then appended to those already in the joined-line record. If the matched coordinate happens to be the last coordinate of the matched line segment, then the coordinates of the matched segment are written to the joined-line record in reverse order. The last coordinate written to the joined-line record becomes the new search coordinate and the match search process begins again. JOINZ continues following a line through the zones, joining the segments as it goes, until no match coordinate for the search coordinate is found. When this occurs, the joined-line record is written to a joined-line disk file and the line record is closed. The sequential search is then reinitiated, and the line joining cycle begins again. All lines in the file are joined in this manner.

JOINZ joined the 475 zones of the Unionville index contour data set in 9 minutes. The number of index contour lines input to the program was 1,831 and the number output was 330. The intermediate contours were processed in 54 minutes, and the 6,910 intermediate contour lines input were reduced to 1,198 upon output.

DATINF

The final step in the R/V conversion process is to build an Intergraph design file with the line elements contained in the joined-line file created by JOINZ. In order to speed the interactive editing and tagging procedure on the Intergraph, it is also necessary at this stage to filter out coordinates or vertices of each line which are not essential to retention of line definition. The smaller the design file in terms of number of vertices, the faster interactive editing proceeds. DATINF processes the data set a single line at a time. It reads a line record from the joined-line file, filters the vertices, and performs a simple format conversion on the line data before writing it to the design file. DATINF processed the Unionville index contours in 3 minutes and the intermediate contours in 7 minutes. The number of vertices defining the 1,528 index and intermediate contour lines was filtered down to 69,670. The entire contour data set occupied 1,470 blocks (256 words per block) of the Unionville design file.

VECTOR EDITING AND ATTRIBUTE TAGGING

Vector editing and attribute tagging are performed interactively on the Intergraph System in the design file generated by DATINF. Editing and tagging operations are made utilizing an Intergraph Design Station and its associated edit functions. The design station is composed of: a digitizing table, menu tablet, free-floating cursor, alphanumeric keyboard, and twin CRTs. Editing functions are initiated via cursor through the command menu. For repetitive operations such as attribute tagging, user commands have been written to automate the procedures. An Intergraph user command is simply a user-defined procedure in which a series of individual system functions are combined and executed under a single command.

Discussion here will be limited to the editing and tagging of the Unionville contour data set to be processed for entry into the Digital Elevation Model (DEM) DCDB. Because the Unionville contour set underwent extensive editing on the Scitex system in raster form, no line editing was required at this stage for DEM production; the only requirement was that each contour be tagged with an elevation.

Contour tagging was done with the aid of a user command. This tagging user command is comprised of three system functions--place text, add to graphic group, and change line symbology. In addition to these functions, the user command is responsible for storing and updating elevation and contour interval values after their initial entry by the operator. Upon initiation, the user command prompts the operator to enter an elevation value and a contour interval value. After entry, the user has the option of incrementing or decrementing the elevation by the contour interval amount with each successive touch of a cursor button. When the elevation has been set to a desired value, the operator then identifies, with the cursor, the particular contour in the design file to be tagged. From this point the functions of the user command are executed automatically. The contour is located and a text string of the elevation is placed in the design file at the point of identification. The text string element and the contour line element are then graphically grouped, thereby linking the two elements together. The user command next changes the symbology of the contour line from a solid line to a short dash so that the tagged contours can be distinguished from the untagged contours. Finally, the elevation value within the user command is automatically incremented by the interval value. At this point the user command is ready for the operator to either identify another contour or to change the current elevation value. The operator, utilizing the source litho or contour film positive as reference, tags all design file contours in this fashion. After tagging is completed and the elevation tags have been verified through visual inspection, the data are ready for extraction and entry into a DEM processing system.

Tagging and verification of the Unionville contours required approximately 32 man-hours.

CONCLUSION

Development of the raster data acquisition and processing system has brought the National Mapping Division a step closer to solving the problem of converting more than 40,000 published sheets to digital form in a timely, cost efficient manner. The system, though operational, is still in the early stages of development. It has, at this point, served to establish the feasibility of raster scanning and processing as a viable method of data capture. The scanning of high-volume, contour map separates has proven faster and more accurate than manual digitization.

COMPUTER-ASSISTED SPATIAL ALLOCATION OF TIMBER HARVESTING ACTIVITY

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ABSTRACT

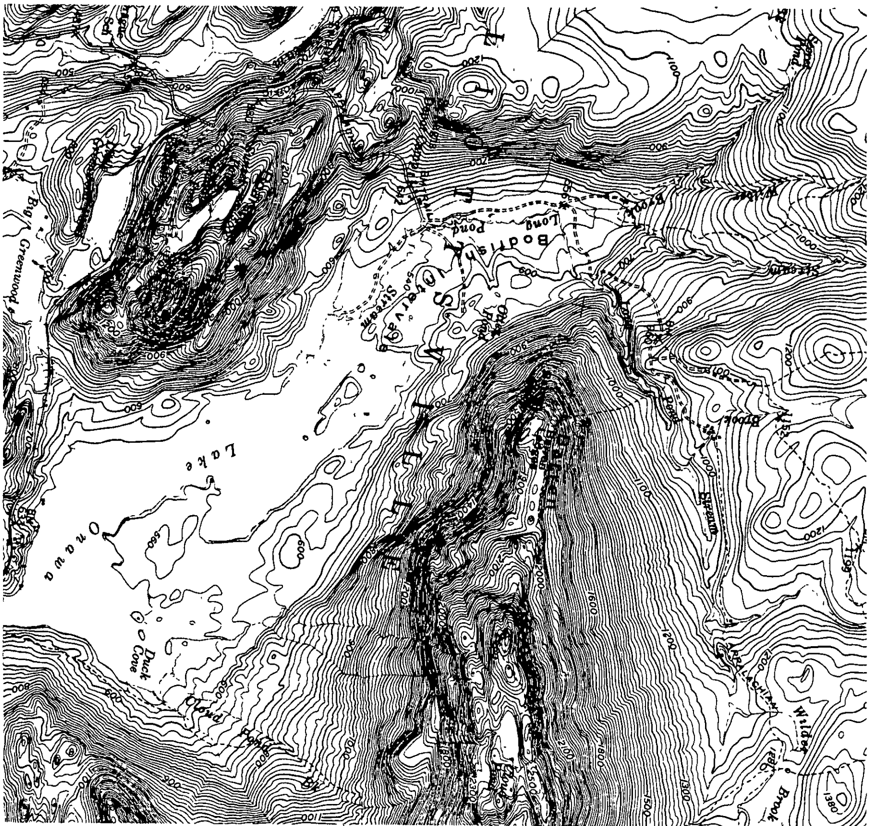
Mathematical optimization techniques have long been used to develop schedules for timber harvesting activity. These techniques provide a rational basis for decisions concerning what to cut and when to cut it. They seldom deal, however, with the issue of where. This paper describes an attempt to combine mathematical optimization techniques with the spatial allocation capabilities of a geographic information system in order to develop an on-the-ground harvesting plan. Methods are described in cartographic rather than mathematical terms and examples are drawn from a case study involving forest land located in central Maine.

INTRODUCTION

Shown in Figure 1 is a topographic map of an area in central Maine. The area includes approximately 22,000 acres of essentially undeveloped forest, lakes, and mountainous New England topography. In Figure 2 is a cartographic overlay of this area generated as part of a timber harvesting plan. The overlay identifies acreage to be harvested in the third decade of a 10-decade harvesting schedule. It also shows the pattern of logging roads to be constructed by that point in time.

The harvesting plan (Tomlin 1981) from which Figure 2 is taken is one which attempts to maximize selected economic returns associated with harvesting over time. To do so, it must account for changes in the value of timber over long periods due to economic as well as biological growth. It must also account for the costs associated with access to the timber involved.

The first of these problems is one of temporal dimensions. It is essentially a matter of optimal scheduling. Here, this is done by expressing changes in the nature and value of the forest resource in the form of an IRAM (Gould 1977) model. Linear programming (Dantzig 1963) is then used to derive optimal harvesting schedules. Results for the first three decades of the proposed plan call for the harvesting of 1284 acres of mixed-age hardwoods, 366 acres of older hardwoods, 165 acres of mixed-age softwoods, 131 acres of



NORTH 6° WEST ⟶ 1 MILE

Figure 1. Portion of the USGS topographic map of an area in central Maine used to demonstrate a computer-assisted technique for allocating timber harvesting activity. Cartographic overlays of the area are shown in Figures 2 through 6.

younger softwoods, and 635 acres of younger mixed growth in decade one; 1556 acres of mixed-age hardwoods, 95 acres of older hardwoods, 296 acres of mixed-age softwoods, and 635 acres of mixed-age mixed growth in decade two; and 1561 acres of mixed-age hardwoods, 90 acres of younger hardwoods, 296 acres of mixed-age softwoods, and 635 acres of younger mixed growth in decade three.

The problem of efficiently accessing timber is one of spatial as well as temporal dimensions. It is a matter of determining when to cut where and how to get there. In the present context, this must be done in a manner which accommodates the scheduling requirements outlined above while minimizing transportation expenses. This paper describes an approach to the problem which utilizes digital cartographic modeling techniques (Tomlin in preparation).

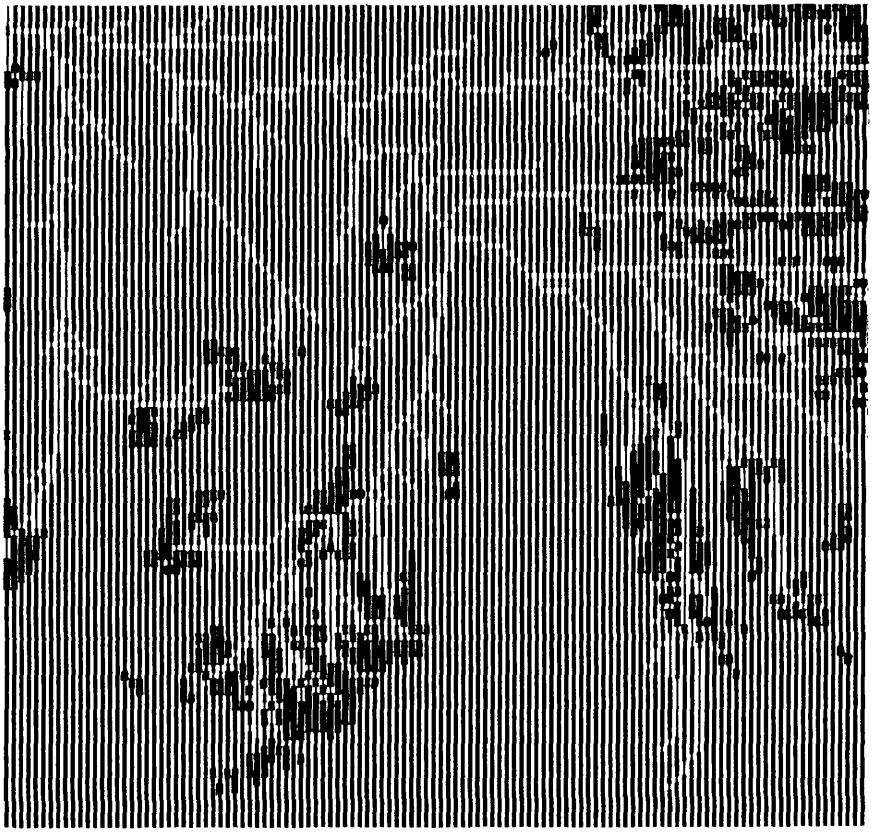


Figure 2. Cartographic overlay showing areas to be harvested and logging roads to be constructed as part of a timber harvesting plan. Lighter tones indicate roads. Darker tones indicate areas to be harvested in one particular decade.

METHODOLOGY

The data processing capabilities used for this purpose are those of the Map Analysis Package (Tomlin 1980), a geographic information system descending from IMGRID (Sinton 1976), GRID (Sinton and Steinitz 1969), and SYMAP (Fisher 1963). Like its predecessors, the Map Analysis Package is an overlay mapping system employing a grid cell data structure. Most significantly, it features an ability to flexibly transform and combine map overlays through sequences of algebra-like operations (Tomlin and Tomlin 1981).

To spatially allocate timber harvesting activity, these operations are used first to estimate the cost of providing access to each grid cell in the study area, then to prioritize harvestable areas on the basis of those access costs, and finally to locate the routes of minimum-cost access to those areas.

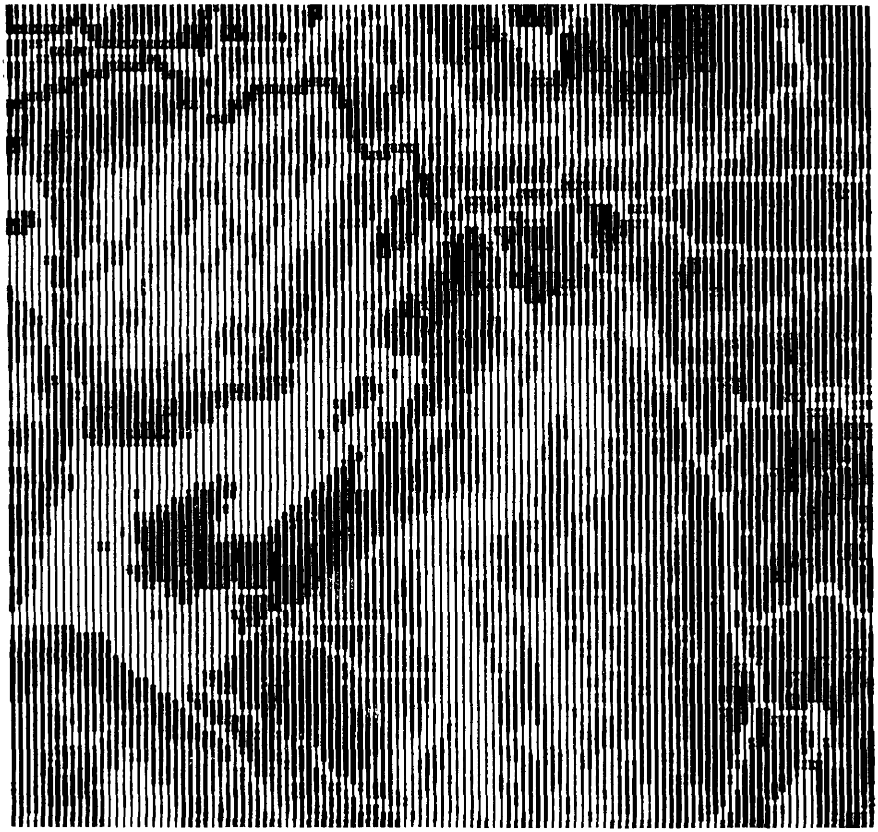


Figure 3. Cartographic overlay showing areas of varying suitability for the construction of logging roads. Lighter tones indicate areas where characteristics such as steepness or wetness result in higher incremental transport costs.

Estimating Access Cost

To estimate the cost of providing logging road access throughout the study area, each grid cell must first be characterized in terms of the incremental cost of constructing a segment of roadway at that particular location. Given a point of access to the study area, these incremental costs are then accumulated as distance from that point increases. Finally, the cumulative transport costs which result are distributed over the entire area ultimately served.

Incremental transport cost. One estimate of logging road construction costs in the central Maine study area ranges from $20,000 to $70,000 per mile depending on site conditions. In general, costs of road construction are greater in areas that are steep, wet, developed, not easily acquirable, and/or subject to legal restriction. An overlay summarizing these conditions in the study area is presented in Figure 3.

To create the overlay shown in Figure 3, overlays respectively describing topographic slopes, water bodies, roads and trails, structures, ownerships, and regulation districts are first transformed into new overlays by assigning cost coefficients to geographic characteristics. In transforming the water bodies overlay, for example, coefficients are assigned to indicate that open water is more costly than wetlands or streams which, in turn, are more costly than dry land. The resulting overlays are then mathematically superimposed to characterize each cell in terms of a single value.

Cumulative transport cost. Next, one or more points of access to the study area must be identified. For this exercise, it is assumed that the study area is to be accessed from a single point located at its upper left corner. The cost of accessing any other point within the study area can then be expressed in terms of proximity to this upper left corner. Here, however, proximity is measured not in terms of miles as the crow flies but in terms of dollars as the logging road extends. The dollars involved are those of the incremental transport cost ovelay presented in Figure 3.

One way to measure proximity in terms of this travel-cost metric (Warntz 1965) involves treating distance as an expression of the motion of waves that are subject to refraction and diffraction as they pass through media of varying density. In this case, the media involved correspond to areas defined by incremental transport costs. The effect can be approximated as outlined below.

STEP 1. ASSIGN A "PROXIMITY VALUE" OF 0 TO THE GRID CELL ASSOCIATED WITH THE POINT OF ACCESS AND A VALUE OF 99999... TO ALL OTHER CELLS.

STEP 2. IDENTIFY THE GRID CELL ASSOCIATED WITH THE POINT OF ACCESS AS "ACTIVE."

STEP 3. COMPUTE, FOR EACH CELL ADJACENT TO THE ACTIVE CELL, A VALUE EQUAL TO THE SUM OF THE INCREMENTAL TRANSPORT COST OF THAT NEIGHBOR (TIMES 1.4142 IF THE NEIGHBOR IS DIAGONALLY ADJACENT) AND THE PROXIMITY VALUE OF THE ACTIVE CELL. IF THE RESULTING VALUE IS LESS THAN THE CURRENT PROXIMITY VALUE OF THE NEIGHBORING CELL, REPLACE THE HIGHER VALUE WITH THE LOWER.

STEP 4. ONCE EVERY CELL HAS BEEN ACTIVE, STOP.

STEP 5. OF THOSE CELLS THAT HAVE NOT YET BEEN ACTIVE, IDENTIFY THE ONE (OR ONE OF THOSE) WITH THE LOWEST CURRENT PROXIMITY VALUE AS THE NEXT CELL TO BE ACTIVE.

STEP 6. RETURN TO STEP 3.

This technique (Tomlin 1977) is comparable to those associated with the generation of minimum spanning trees in graphs. Its effect can be seen in the overlay of cumulative transport costs presented in Figure 4.

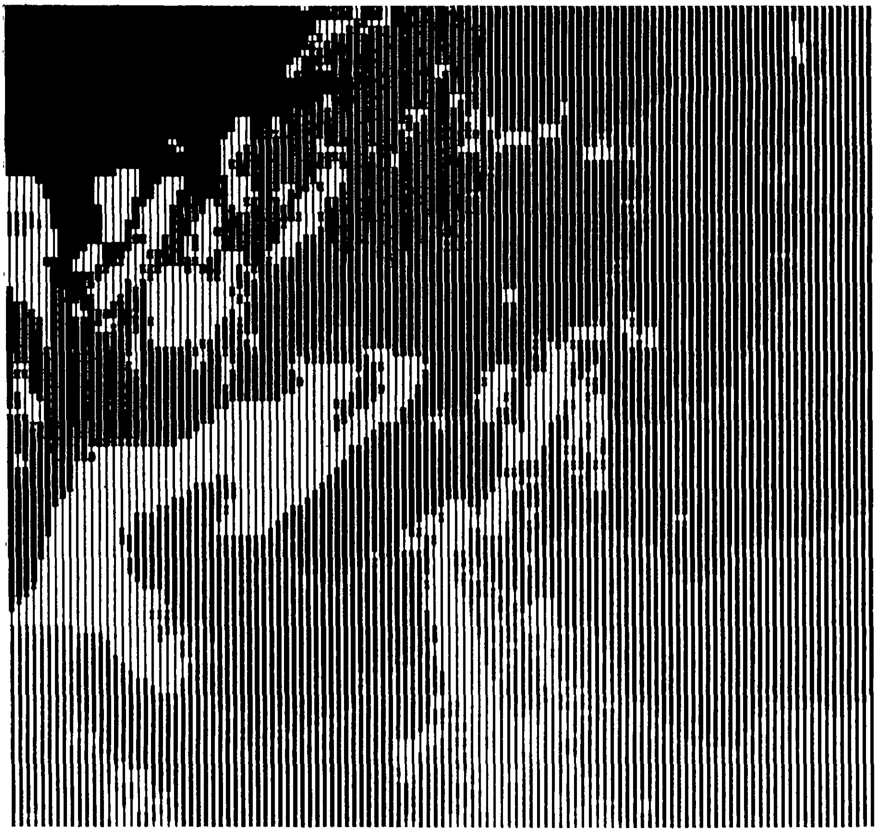


Figure 4. Cartographic overlay showing areas of varying travel-cost proximity to the upper left corner of the study area. Lighter tones indicate areas of higher cumulative transport costs.

Cumulative transport cost per area served. The cumulative transport cost associated with each grid cell of the overlay shown in Figure 4 indicates the lowest possible cost of constructing a logging road from the upper left corner of the study area to that particular cell. Note that if two or more cells are to be harvested, however, the total cost of providing access to those cells as a group may be considerably less than the sum of their individual costs. This will be true whenever two or more cells can be accessed using a common segment of roadway. In this case, the cost of constructing the segment involved can, in effect be shared by all cells ultimately served.

By applying this reasoning to all harvestable cells within the study area, each cell can be characterized in terms of its access cost as part of the overall road construction package. To do so, each cell must first be characterized according to the total acreage that would be served by a segment of logging road through that cell. The incremental transport cost associated with each cell is then divided by this total to yield an incremental cost-to-benefit ratio. Finally, the resulting cost-per-benefit values are accumulated in the manner of the travel-cost proximity measuring technique outlined above.

To estimate the acreage that would be served by a segment of roadway through each cell, a technique is used which, in effect, determines the minimum-cost path from every cell of harvestable timber to the upper left corner of the study area and then computes the number of paths ultimately passing through each intervening cell. This can be done as outlined below.

STEP 1. ASSIGN A "TRAFFIC COUNT" OF 0 TO ALL GRID CELLS.

STEP 2. ASSIGN A "TIMBER VOLUME" OF 1 TO ALL HARVESTABLE CELLS AND 0 TO ALL OTHER CELLS.

STEP 3. DETERMINE, FOR EACH CELL, THE ADJACENT NEIGHBOR(S) WHOSE CUMULATIVE TRANSPOST COST B MAXIMIZES THE QUANTITY (A-B)/C WHERE A IS THE CUMULATIVE TRANSPORT COST OF THE CELL ITSELF AND C IS A VALUE OF EITHER 1 OR 1.4142 DEPENDING ON WHETHER OR NOT THE NEIGHBOR INVOLVED IS DIAGONALLY ADJECENT. IF THE CUMULATIVE TRANSPORT COST OVERLAY IS VIEWED AS A THREE-DIMENSIONAL SURFACE ON WHICH HIGHER VALUES ARE ASSOCIATED WITH HIGHER ELEVATIONS, THESE WILL CORRESPOND TO "STEEPEST DOWNHILL" NEIGHBORS.

STEP 4. ADD THE TIMBER VOLUME OF EACH CELL TO ITS TRAFFIC COUNT AND THEN TRANSFER THAT TIMBER VOLUME TO THE CELL'S STEEPEST DOWNHILL NEIGHBOR(S), DIVIDING IT AMONG THEM IF THERE ARE MORE THAN ONE.

STEP 5. WHEN THE TRAFFIC COUNT ASSOCIATED WITH POINT OF ACCESS TO THE STUDY AREA IS EQUAL TO THE TOTAL NUMBER OF HARVESTABLE CELLS, STOP.

STEP 6. RETURN TO STEP 4.

The process, in effect, drains timber over the three-dimensional surface of cumulative transport cost values. This is done in recognition of the fact that each cell's steepest downhill neighbor on that surface is also next on the path of minimum-cost from that cell to the upper left corner.

By dividing the incremental transport costs of Figure 3 by the acreage values of Figure 5 and accumulating the resulting cost-to-benefit ratios (in the same way Figure 3 values were accumulated earlier to create the overlay in Figure 4), travel-cost proximity can now be measured in terms of cumulative transport costs per area served. This effect can be seen in Figure 6.

Figure 5. Cartographic overlay showing the amount of timber that would pass through each point if every harvestable acre were to be accessed by its own minimum-cost path. Darker tones indicate areas of higher transport volume.

Prioritizing Harvestable Areas

Given the overlay of harvesting costs presented in Figure 6, the task of prioritizing harvestable areas reduces to one of sorting the stands of each forest type by this measure of travel-cost proximity. As a result, the areas to be harvested first tend to be those which are not only nearby but which also pave the way (literally) for the greatest amount of harvesting opportunity in subsequent decades. This is what accounts for the pattern of harvesting illustrated in Figure 2.

Locating Access Routes

Once the areas to be harvested in a particuler decade are located, access routes to those areas can be established by following the veins of higher traffic on the overlay shown in Figure 5. The resulting pattern of logging roads is one which attempts to minimize hauling distances as well as the ultimate cost of the harvesting transportation network.

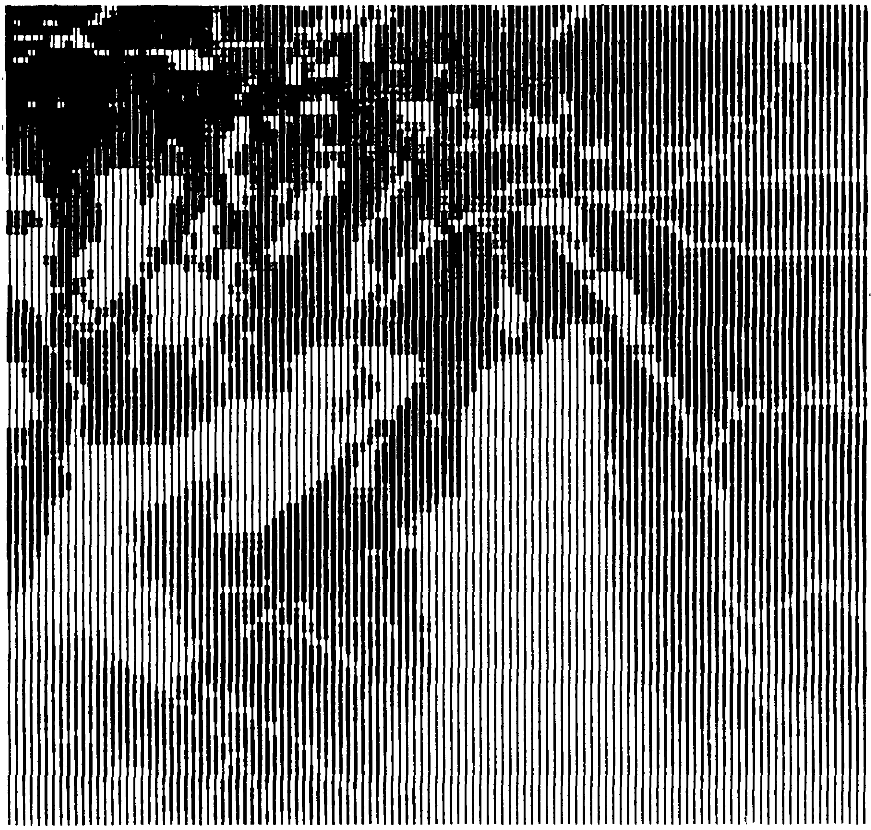


Figure 6. Cartographic overlay showing areas of varying travel-cost proximity to the upper left corner of the study area. Lighter tones indicate areas of higher cumulative transport costs distributed over areas served.

CONCLUSION

By applying this allocation technique over several decades, a reasonable pattern of timber harvesting units and access routes can be identified. In doing so, however, it becomes apparent that the spatial distribution of forest types in a given study area may well preclude strict adherence to a harvesting schedule established through non-spatial optimization. If 99 of a prescribed 100 acres to be harvested, for example, are located within a half-mile radius while the 100th acre of the forest type called for is five miles away, it may be wise to reconsider. On the other hand, if access costs can be estimated, they can often be incorporated into the scheduling process as linear programming constraints.

This paper has described a digital cartographic modeling technique for the spatial allocation of timber harvesting activity. The technique described, albeit simplistic, suggests that automated procedures can effectively allocate over space as well as time. It also suggests that, by emphasizing graphics, this can be done in a way which anticipates the heuristic nature of harvest planning in general.

ACKNOWLEDGMENTS

Much of the work described in this paper was carried out under the direction of Dr. Ernest M. Gould, Jr. at the Harvard Forest. Presentation slides were prepared by Glenn Hansen and Doug Johnston at the Harvard Graduate School of Design using IMAGO MINDI, a color relief-shading program developed by Denis White at the Harvard Laboratory for Computer Graphics and Spatial Analysis.

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A COLOR SYSTEM FOR COMPUTER GENERATED CARTOGRAPHY

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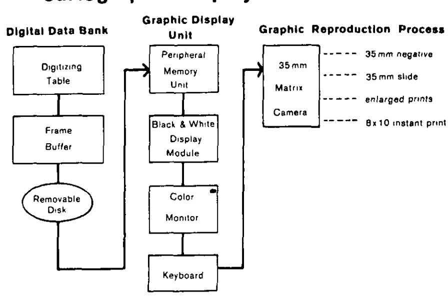
ABSTRACT

Color is being used more often as a technique to represent entities within a Cartographic representation. Color, in the context of a map, if understood and properly manipulated, enhances and clarifies the portrayal of that information.
This being the age of the comupter and advancing technology, there arises new applications for fundamental theories. In this study basic color theory is applied in the developing of a color system for computer generated cartography.
The color is derived systematically through a numerical process. By using this system, the colors, once established can be repeated and reproduced through a computer driven 35mm matrix camera. The perceptual difference between color are achieved by visually selecting a series of color palettes. With numerical coding the colors can then be matched and displayed ina map format for testing. This presentation demonstrates the application of basic color theory concepts using this approach.

Geographic Data Base

The Cartographic Display Process begins with the establishment of the geographic data base. A multi-faceted geographic data base is established for storage and retrieval of cartographic information. Initially, cartographic data is entered by means of a digitizing table and cursor, or by a direct image transfer, and stored in digital form. The information is recorded in polygon strings of X-Y coordinates. It is then organized and edited through the computer and temporarily stored on a removable magnetic disk. The digital information stored on the disk is encoded through the graphic display unit. The peripheral memory unit, which is attached to the cpmputer, transforms the infor mation to a visual graphic image. This image is projected through the black and white display module. An image can remain in black and white or it can be transferred to the color monitor, which displays the grey tones in color. The image displayed, can be reproduced through the matrix camera in black and white or color.

Cartographic Display Process



Graphic Reproduction Process

The matrix camera is a 35mm camera mounted on a light-tight box which houses a computer driven CRT Monitor. This CRT monitor is used to pick up the graphic image, displayed in raster form, in grey tone values. Through a mirroring projection system the CRT image is composited through sequential red, green and blue filter exposures and copied by the 35mm camera or the single sheet film magazine mounted on the front and top, respectively, of the light-tight box. The image can be reproduced in color or black and white on different materials: 35mm film, positive and negative; paper print enlargments can be made from the negatives; or individual sheet film can be used in the single sheet film magazine for an 8x10 instant paper print.

Basic Color Theory

To understand the process of producing color on the color monitor, one must also understand the concepts of color theory.

The physics of light demonstrates that white light projected through a prism can be broken into the color spectrum. Color theory demonstrates that there are basically two methods of producing and mixing colors, the subtractive and additive methods.

The subtractive method of producing color begins with a source of white light which contains all colors of the spectrum. Through absorbing particular colors, those colors absorbed are subtracted from the spectrum, allowing for the remaining color to be transmitted.

Subtractive primary mixing colors are: Yellow, (Slide #2) Cyan, (Slide #3) and Magenta. (Slide #4) Through the mixing of these primary colors, secondary colors are produced. Yellow and Cyan combine to produce Green; Cyan and Magenta produce Blue; Magenta and Yellow produce Red. All colors combined produce Black.

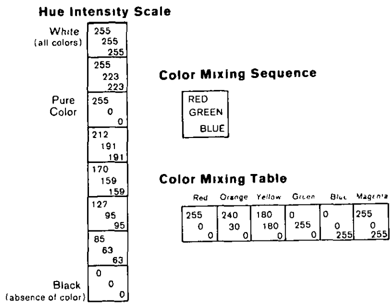
This method of color mixing is used in offset lithographic printing. The mixing of color pigments is achieved through over printing of the primary colors. Cartographers use this method of color mixing for map reproduction.

The opposite of this is the additive method which starts with the absence of light, blackness. Color is achieved by means of projecting the pure color. Although there are different ways of projecting color, the most common is by projecting white light through a colored filter. The additive color mixing method uses the primary color: Red, (Slide #5) Green, (Slide #6) and Blue, (Slide #7) which in color theory, are the subtractive secondary colors. The mixing of the primary colors produce the additive secondary colors. The mixing of the primary colors produce the additive secondary colors: Red and Green produce Yellow; Green and Blue produce Cyan; and Blue and Red are combined to produce Magenta. These secondary colors are the subtractive primary colors. All colors combined produce white light.
This method of color mixing is used in electronically projected color, for example, CRT monitors and T.V.

The color monitor used for viewing the display employ's the additive process of producing color. Pure colors, Red, Green and Blue are electronically transmitted and the monitor is calibrated to incorporate specific color charateristics. The intensity of a pure color is calibrated by assigning a numerical value range of 0 to 255, with zero being no color and 255 the greatest luminosity of the hue.

This calibration is equivalent to screen printing, with 255 equalling 100% of a saturated hue. Primary colors in their purest state are transmitted by individual color channels on the color monitor at an in intensity value of 255, and through a color mixing proceedure, all other colors are derived.

Color Characteristics



An eight step Hue Intensity scale was established to demonstrate the progression of tints and shades. The scale shows the numerical values of a single color intensity range. The pure color was placed in step three, then other primary colors were added or subtracted for a color range from black to white. To produce a desired color there are two controlling variables; the intensity of a color and the mixing of colors.

Once the primary colors are established a numerical interpolation is calculated to produce secondary and all other colors. The color mixing table shows the additive process of mixing primary colors, to achieve additional colors for example, to produce Magenta, equal parts of Red and Blue are combined; Yellow is produced by a mixture of Red and Green; and a greater value of Red is used to produce an Orange.
Through this process a logarithmic interpolation between primary colors was set up to produce a 30 step color spectrum. (Slide #9 Color Spectrum)

Selection of Usable Color Palettes

The next step was to establish a color value spectrum. An 8x8 grid was displayed on the color monitor. The color mixing array appears on the X axis and the Y axis represents the color intensity scale. With this display the task of recording color combinations was possible. The colors were reproduced and preserved on color slide film, in positive form. Usable color palettes were selected from numerous amounts of color swatches, by using a trail and error process.

Although there can conceivably be hundreds of different color combinations produced, one must choose colors which can be perceptually distingushable. To achieve this the series of color palettes were visually selected through a masking technique. With this method each color could be isolated from the next. A series of eight colors were chosen for each palette and once a color was visually chosen it was then matched up numerically.

Establishing of Color Palettes

The color palettes were selected and coded. The following are the initial color palettes which were established: Series of Grey's (Slide #10) here the initial 32 step color run was calculated; a second 8 color run (Slide #11) was selected by pulling every other fourth color. Saturated Hues (Slide #12) light, Medium, (Slide #13) and Dark. (Slide #14) The three palettes displayed together (Slide #15) demonstrate the progression from light to dark these palettes contain colors having the same intensity value, yet saturated in their hue.

Pastel Hues Light, (Slide #16) Medium, (Slide #17) and Dark (Slide # # 18) The Comparative series (Slide #19) showing all three color palettes were developed next. These palettes have colors containing a large quantity of white light. Also developed are a Series of Brown's (Slide #20) 16 color run, 8 color run (Slide #21) and a 4 color run. (Slide #22) Also displayed is the Comparative series. (Slide #23)

Color Application and the Process of the Color Display

Once the color palettes were established, they could be applied in a map format. (Slide #24 Digital grey scale map with 32 step grey series palette) First the digital graphic image is brought up on the color monitor in grey tone values with a selected palette appearing with the graphic image. (Slide #25 Grey scale map with series of Brown palette) The color palettes are located along the top or the bottom of the image frame. (Slied #26 Grey scale map with color spectrum) Through a pointing technique, color can be assigned to the areas within the body of the map.

With keyboard at hand for the input, one simply points with the joy stick, to the color desired in the palette, keys in a return then points to the polygon to be colored, and keys in another return. (Slide #27 color map with palette display) The selected color then appears in that polygon and all other polygons having the same value.

It then becomes a quick task to compose a color map which is a suitable representation of the information. If after the map is composed one is not satisified with those colors used, the colors may be changed through the same process. Once a fully composed color map is established and is deemed satisfactory, it can be preserved by the different reproduction techniques of the matrix camera.

Conclusion

The field of Cartography is expanding rapidly and influencing disciplines such as Computer Technology, Mathematics, Psychology, and the Graphic Arts, are being applied to Cartographic techniques. It is no longer sufficient to have training in only one area. Through the study and practical use of cartography, one must incorporate the many diverse disciplines. As computer technology advances there are new applications for fundemental concepts. This documentation demonstrates one study of Color Theory Concepts as they can be applied to computer enhanced Cartographic Techniques.

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ENVIRONMENTAL ASSESSMENT WITH BASIS

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ABSTRACT

The use of automated techniques for environmental assessment has developed significantly in the past two decades. Although there has been equally rapid advancement in the practice of geographic data handling, the techniques of this field have been infrequently applied to assessment projects. This is particularly true of large area data systems created for regional or statewide planning applications. One regional data base - BASIS in the San Francisco Bay Area - has recently been used for several local and subregional environmental assessment projects. These applications illustrate the technical and institutional barriers which must be overcome to use geographic data bases in environmental assessment work.

INTRODUCTION

During the past two decades, there has been a growing awareness of man's relationship to the natural and manmade environment. Events such as earthquakes and volcanic eruptions have shown the awesome destructive potential of natural forces. Pollution problems and chemical spills act as frequent reminders of other dangers. A greater understanding of ecological relationships has developed, and this understanding has increased the ability to systematically analyze proposed human actions and to predict their effect on the natural and human environment.

Federal and state legislation to require such study (beginning with the National Environmental Policy Act of 1970) has lead to the development of a discipline which studies the potential environmental effects of human actions and proposes steps to mitigate these effects. This field, known as environmental assessment, has created many complex techniques for predicting impacts and for identifying mitigation measures.

Developments in the field of geographic data handling have been equally rapid in this period. Advances in computer hardware and software have made possible innovative applications in such diverse areas as mineral exploration and regional planning; a new acronym, GIS (for Geographic Information System) has come into common use to describe computer mapping and related data storage and manipulation techniques.

Many of these GIS applications have dealt with single environmental issues. There have been, however, few examples of the use of GIS techniques in formal environmental assessment projects. This is somewhat surprising, given the many similarities in the two fields. Both have utilized computer methods heavily. Both deal with data that is largely spatial in nature; a comparison of the data types used in a typical environmental impact report and a major GIS would show much in common. Analytical tools are also similar; each field may deal with operations such as distance calculation and overlaying. Finally, the ability to output mapped data is central to each.

There are clear advantages to a combination of the two disciplines. The concepts of data integration would seem to offer substantial cost savings: one possibility is the creation of a Master Environmental Assessment, where an areawide data base is used to process data for individual projects as they are proposed. The mapping and display capabilities of a GIS offer enhancements to the usual tabular output of environmental models. The use of an areawide GIS would also be helpful in promoting consistent policies; use of the same data by different agencies would tend to remove some of the initial differences in many environmental disputes.

A number of technical and institutional factors have acted to restrict this use. Elements such as data structure, positional accuracy, and the availability of detailed source data for large areas are major technical barriers. Other roadblocks are institutional in nature. Large GISs have usually been built by government agencies; their motivation is the need to study their area of jurisdiction over a long period of time. On the other hand, most environmental assessment work has been performed by private consultants. In most cases, the preparation of an environmental review is treated as a standalone project; data is collected and analyzed for a specific project, with little concern for building a data base which could be used for other applications.

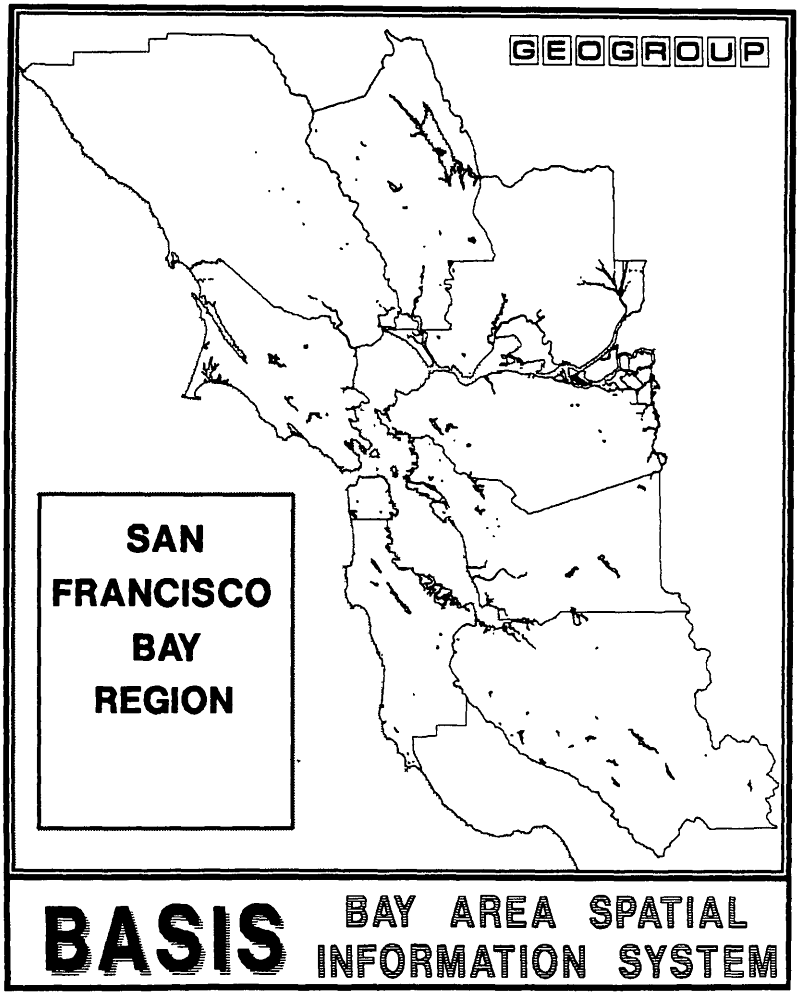
TWO BASIS EXAMPLES

Some recent applications of BASIS, the Bay Area Spatial Information System, illustrate these advantages and limitations. BASIS is a large GIS containing physiographic and socioeconomic data for the 7000-square mile San Francisco Bay region (Figure 1). It was created by the Association of Bay Area Governments (ABAG) in 1974, and was designed to support a variety of regional and local planning applications. The system is now maintained and operated by Geogroup Corporation, and is available for use by both governmental and private organizations.

The primary unit of data representation in BASIS has been the one-hectare grid cell. Coverage of the region (nine counties, the Bay, and ocean areas of interest) requires 2.1 million cells. This hectare cell structure was chosen after extensive debate about anticipated applications of the system. It was clear that a larger cell would support any project that was regional in scope, as well as many which had a subregional scope. Using a smaller cell (or a more complex data structure) would allow for more detailed local studies, but would increase the costs of implementing and maintaining the system. The hectare cell was chosen as a structure that maximized the number of potential applications while assuring a good chance of making the system work. (Since small area projects were a recognized long-term goal, it was concluded that all original data encoding and digitizing would be retained. This would allow for conversion to other structures or to a smaller cell where appropriate.)

BASIS has been used for many applications at the regional scale, as well as a smaller number of local projects (see References). Although these applications have included many which look at complex environmental issues, until recently none approached the breadth of a full environmental assessment project; the focus was always on one type of hazard or resource rather than on bringing together a variety of information for one site. An effort initiated in 1980 has led to the development of two BASIS/environmental assessment programs, one used for projects of *regional* scope and the other directed at the specific needs of one city.

FIGURE 1


GEOGROUP
SAN FRANCISCO BAY REGION
BASIS
BAY AREA SPATIAL INFORMATION SYSTEM

AREA: the Regional Approach
One program is called AREA, for Automated Regional Environmental Assessment. It was designed for use by either regional agencies or local governments, and relies on the BASIS data base to support analytical models and tabulations. This capability was originally developed to summarize impacts of projects which had regional importance, such as noise reduction programs at major airports. Other examples of AREA use include listings of environmental hazards for BART stations and sewage treatment plants, included in a study of earthquake danger to critical lifeline facilities (Figure 2).

A common characteristic of all these regional analyses is the use of one-hectare BASIS cell data. All of the above examples were performed using the cell structure to store environmental data. (Other lifeline data sets, including linear features such as highways and rail lines, were treated as vectors and then overlayed on the cell data.) Most of the effort (and cost) of this type of project is in the data collection phase, since study of regional systems usually requires a large data volume. The analysis itself is straightforward: the location of the critical facility is digitized and converted to the BASIS coordinate system; the cell or cells which it occupies are calculated; and relevant data values are extracted for those cells.

This process has obvious limitations when dealing with specific sites. Since the overlayed environmental data sets are generalized to hectare cells (usually in a dominant area procedure, although data types such as landslides may be coded for the presence of any amount in the cell), precise location of small features can be hidden. The other limiting factors noted in the previous section are often present also; for example, the detail of data classification in a file such as geologic materials is often less than required for a full environmental assessment.

The real value of this application lies in its ability to bring together a large number of potential environmental hazards. Information about different types of hazards exits in different places and in different forms, so it is usually very difficult to summarize and compare risks for a set of sites (such as the lifeline facilities described above). Use of a common data base for storing and analyzing many environmental factors makes it possible to readily access information about each location.

The Petaluma System
The level of analysis described above, while often useful for studies at a regional scale, is clearly inadequate for most local government needs. A city planning agency will usually need data concerning parcel-specific land use and individual street links as part of its analysis. This level of detail is difficult to capture and maintain in regional data bases. Not only is the cell structure unsuitable for parcel data, there are very substantial technical and institutional barriers to the collection of detailed local data by an areawide entity.

Petaluma is a city of 34,000 population located in Sonoma County north of San Francisco. It is widely known for its innovative planning programs, particularly its pioneering efforts in growth management. The city's planning department, needing a more comprehensive tool for environmental assessment as well as for other applications, initiated a project to use BASIS as a foundation for local geoprocessing needs.

FIGURE 2

EXAMPLE OF AREA TABULATION FOR CRITICAL FACILITIES

BART: GLEN PARK STATION	
Surface Rupture Fault Zone	OUT OF ZONE
Maximum Earthquake Intensity	C
Risk of Damage: wood frame	29
Risk of Damage: concrete/steel	46
Risk of Damage: tilt-up	76
Liquefaction Potential	1
Earthquake-Induced Landslide Susceptibility	3
Rainfall-Induced Landslide Susceptibility	2
Dam Failure Inundation	NO
Tsunami Inundation	NO

BART: 16TH ST / MISSION STATION	
Surface Rupture Fault Zone	OUT OF ZONE
Maximum Earthquake Intensity	C
Risk of Damage: wood frame	29
Risk of Damage: concrete/steel	46
Risk of Damage: tilt-up	76
Liquefaction Potential	1
Earthquake-Induced Landslide Susceptibility	1
Rainfall-Induced Landslide Susceptibility	1
Dam Failure Inundation	NO
Tsunami Inundation	NO

BART: CIVIC CENTER STATION	
Surface Rupture Fault Zone	OUT OF ZONE
Maximum Earthquake Intensity	D
Risk of Damage: wood frame	12
Risk of Damage: concrete/steel	13
Risk of Damage: tilt-up	25
Liquefaction Potential	14
Earthquake-Induced Landslide Susceptibility	1
Rainfall-Induced Landslide Susceptibility	1
Dam Failure Inundation	NO
Tsunami Inundation	NO

BART: POWELL ST STATION	
Surface Rupture Fault Zone	OUT OF ZONE
Maximum Earthquake Intensity	D
Risk of Damage: wood frame	12
Risk of Damage: concrete/steel	13
Risk of Damage: tilt-up	25
Liquefaction Potential	14
Earthquake-Induced Landslide Susceptibility	1
Rainfall-Induced Landslide Susceptibility	1
Dam Failure Inundation	NO
Tsunami Inundation	NO

The current Petaluma system integrates regional-level hectare data with more detailed local data sets. The city has digitized parcel boundaries and built a file of parcel attributes (assessor's number, land use, zoning, general plan designation, presence of historic or other special feature) for each parcel. Other locally-produced data (such as vegetation cover) has replaced the BASIS hectare data when available. This combined data base is used to support a series of models and tabulations (Figure 3) which form a preliminary environmental assessment for all proposed development projects in the city. These report sections fall into several categories. Some, such as elevation and vegetation, are simple tabulations of single data sets. Others (such as the tables of earthquake risk and maximum groundshaking shown in Figure 4) represent derived data sets, or the output of models which are stored semipermanently in the BASIS data base. A third category includes models that are rerun for each new project, since they are dependent on characteristics of the proposed development (Figure 5).

The Petaluma system operates in a distributed data base environment. The city's planning department operates a small graphics computer system, which is used for input and storage of all local data sets (parcel file, street network, vegetation, permits). The BASIS data and most of the models are maintained by Geogroup. Project-specific data sets are transmitted over telephone lines as each assessment is run. The city collects basic data on a development schedule and sends it (along with the digitized site boundary and any special files) to Geogroup, where it is combined with BASIS data and selected models are run; results can be printed and mailed or sent back over phone lines. Eventually, copies of relevant BASIS data sets and some of the analytical models will be transferred to the city's computer; this will give it a largely independent capability.

There are several important points to be made about this arrangement. Data sets are collected and stored at the most appropriate organizational level. The city maintains the detailed types such as parcels, while those derived from regional studies are kept at that level. Most institutional problems (such as costing of data base maintenance) are avoided in this way. Also, those characteristics (such as land use) which are subject to frequent change are maintained as a normal function by city staff. Finally, the system is designed to be flexible; only those sections appropriate for a particular project (as determined by the city) are run.

FIGURE 3

AREA / PETALUMA **PROJECT: Westridge** **DATE: February 24, 1982**

LISTING OF REPORT SECTIONS

<u>LAND USE / GENERAL PLAN</u>	EXISTING LAND USE
	GENERAL PLAN DESIGNATION
<u>SITE PHYSICAL CHARACTERISTICS</u>	TOPOGRAPHY
	LANDSLIDES
	VEGETATION
	GEOLOGIC MATERIALS
	SOIL ASSOCIATIONS
<u>HAZARDS</u>	SLOPE STABILITY
	LIQUEFACTION POTENTIAL
	DAM FAILURE INUNDATION AREAS
<u>EARTHQUAKE HAZARDS</u>	FAULT STUDY ZONES
	MAXIMUM EARTHQUAKE INTENSITY
	RISK OF DAMAGE
<u>HYDROLOGY</u>	ANNUAL PRECIPITATION
	BASINS ON SITE
	STREAM STATUS
<u>WATERSHED DATA</u>	PRIMARY STREAM
	RECEIVING WATERS
	EXISTING LAND USE
	SURFACE RUNOFF IMPACT
<u>EROSION</u>	EROSION CALCULATION
	MITIGATION
<u>WATER SUPPLY</u>	WATER SOURCES
	WATER CONSUMPTION FACTORS
	DEMAND CREATED BY PROJECT
	STATUS OF WATER SUPPLY AT SITE
	MITIGATION: WATER CONSERVATION
<u>WATER QUALITY / SEWAGE DISPOSAL</u>	WASTEWATER
	STATUS OF SEWERAGE AT SITE
	RECEIVING WATERS
	IMPACTS
<u>SOLID WASTE</u>	COLLECTION INFORMATION
	DISPOSAL SITE INFORMATION
	WASTE GENERATION
<u>FIRE PROTECTION</u>	EMERGENCY RESPONSE ZONES
	STATUS OF WATER SUPPLY AT SITE
	WILDFIRE HAZARD
<u>EDUCATION</u>	SCHOOLS AFFECTED BY PROJECT
	STUDENTS GENERATED BY PROJECT
<u>ENERGY</u>	ENERGY CONSUMPTION FACTORS
	SOLAR WATER HEATING OPTION
<u>TRAFFIC</u>	BASE YEAR
	TARGET YEAR ALTERNATIVES
<u>AIR QUALITY</u>	BASE YEAR
	TARGET YEAR ALTERNATIVES

FIGURE 4

AREA / PETALUMA PROJECT: Westridge

EARTHQUAKE HAZARDS

FAULT STUDY ZONES

	(Acres)
OUTSIDE STUDY ZONE	12

MAXIMUM EARTHQUAKE INTENSITY

	(Acres)
A (4)-Very Violent	0
B (3)-Violent	0
C (2)-Very Strong	12
D (1)-Strong	0
E (0)-Weak	0
-Negligible	0

RISK OF DAMAGE

Expected risk of ground-shaking damage for building types proposed for site. Estimate based on statistical procedures using major fault earthquake recurrence intervals and average building damage.

Percent Damage of Present Value		Wood Frame Dwellings (Acres)	Concrete/Steel Buildings (Acres)	Tilt-Up Concrete (Acres)
0.0-1.0 %	Moderate	0	0	0
1.1-2.0 %	*	12	0	0
2.1-3.0 %	*	0	0	0
3.1-4.0 %	High	0	7	0
4.1-5.0 %	*	0	5	0
5.1-6.0 %	*	0	0	0
Over 6.0 %	Very High	0	0	12

FIGURE 5

AREA / PETALUMA PROJECT: Fireman's Fund

AIR QUALITY

2000 - TARGET YEAR WITH PROJECT

CONTAMINANT	AVERAGING TIME	STANDARDS (ug/m3)	REGIONAL IMPACTS (ug/m3)	LOCAL IMPACTS (ug/m3)
CO	1 hour	40,000	1	1400
	8 hour	10,000	0	766
HC	3 hour	160	0	84
NO2	1 hour	470	0	189
	1 year	100		17
SO2	1 hour	1,310	0	21
	24 hour	105	0	8
	1 year	80		1
TSP	24 hour	100	0	11
	1 year	60		2

SENSITIVE RECEPTORS AFFECTED

Name	CO Concentration at receptor 1 hour (ug/m3)	CO Concentration at receptor 8 hours (ug/m3)
CASA DE ARROYO 2	5348.	700.

CONCLUSIONS

It is clear that major advantages can be derived from the application of GIS techniques to environmental assessment. It is equally obvious that the advantages are balanced by several limitations. These include technical factors, which are based on the nature of current GIS practice, and institutional factors, which arise from the organizational setting in which the two fields have developed.

How can geographic data handling systems be made more useful for assessment work? A first requirement is a clear understanding by GIS designers that assessment applications are different in data needs and resolution from projects that are regional in scope. Also, more attention must be paid to the fundamental issues of map accuracy and data sources. Data base structures must allow for distributed data collection and storage.

These technical barriers can normally be overcome; the availability of better computer hardware and software will continue to provide powerful new tools. Institutional factors are likely to prove more difficult. A major issue is overcoming the one-shot nature of most assessment data collection; viewing scattered projects as components of an areawide data base requires a major change in the way most GISs are designed and implemented.

It seems clear that the GIS concept offers much potential to support environmental assessment projects. It cannot replace the field work and detailed analysis required for impact assessment of a small site, but it can provide a useful framework for spatial data handling. Computer mapping techniques can greatly improve the display of source data and of model output. The advantages of this combination - more effective presentation of results, potential cost savings, and a greater consistency of information for making decisions - are strong arguments for better integration of the two disciplines.

REFERENCES

One of the better treatments of environmental assessment techniques is Environmental Impact Analysis Handbook, edited by John G. Rau and David C. Wooten (McGraw-Hill, 1980). The best method for understanding assessment practices is to review a variety of impact reports for different types of projects (and, if possible, for different geographic areas). Reports are usually filed with a state or regional clearinghouse agency.

Descriptions of BASIS applications are available from Geogroup Corporation or from the Association of Bay Area Governments. Several ABAG reports on earthquake mitigation are particularly good illustrations of GIS techniques being used at different levels of geography. Other examples of BASIS application to environmental assessment work include models of sites for disposal of hazardous solid wastes, airport noise analysis, and listings of environmental constraints on vacant industrial sites.

Information about applications of the Petaluma system can be obtained from the city's Planning Department.

REFINEMENT OF DENSE DIGITAL ELEVATION MODELS

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ABSTRACT

The Topographical Survey Division of the Surveys and Mapping Branch, Energy, Mines and Resources, Canada, employs dense digital elevation model (DEM) data for the production of hypsographic overlays for conventional and orthophoto maps.

The Gestalt Photomapper (GPM II/3), installed as a production system since summer of 1977, uses computer controlled electronic scanning and image correlation techniques to produce both orthophotos and dense digital elevation models at high speeds. Discontinuities caused by built-up areas and water bodies, poor image quality, shadows, and steep terrain slopes create anomalies in the DEM which require special data filtering and refinement techniques.

A complex DEM post data-processing system has now been developed to remove such anomalies and inlcudes various sub-programs which operate in Interactive and/or Batch processing modes. The key components of the system are:

* interactive filtering of erroneous observations from the raw DEM's produced by GPM II/3, and editing noise from scanning over water surfaces,
* generating of elevations from a global grid oriented to the UTM coordinate system,
* edit of DEM's for elevation biases, and the enhancement of the hypsographic data to achieve cartographically acceptable contour/ stream re-entrants,
* generating of a structured global DEM data base with the capability of integrating height information from other sources,
* production of hypsographic overlays for conventional and ortho-photo maps.

In order to illustrate the advantages of using the refinement process, several samples are included.

INTRODUCTION

The Gestalt Photomapper (GPM-II), installed at the Topographical Survey Division in 1977, use electronic image correlation to measure parallaxes and produces automatically and simultaneously three products: an orthophoto negative, a contour overlay and a digital elevation model (DEM). The GPM divides the stereomodel into about one thousand 9 by 8 mm scanning area. Depending on the mask size used to print the orthophoto and contour overlay, a matrix (40 by 40, 32 by 32, or 24 by 24) of elevations (patch) in each scanned area is generated. The grid spacing of the matrix is fixed at 182 μm at the photo scale.

In other words, the GPM can produce approximately one million grid elevations in each DEM. For topographic mapping applications, this represents a dense grid on the ground, e.g. using photography at a scale of 1:60 000, and a grid spacing of approximately 10.9 metres.

Due to the limitations of the automatic photogrammetric process, erroneous elevations may occur in the DEM in areas covered with large water surfaces, glacial features, elevation biases, shadows and forests.

A system for the post-processing of data was developed in the Division and is fully operational since 1979 to refine the dense DEM and to integrate the DEM's into our digital mapping system for the production of 1:50 000 topographical maps and the National Digital Terrain Elevation Data Base. The main components of the post-processing system are:

- erroneous data inspection and verification
- DEM interactive editing
- DEM standardization
- further refinement to global grid elevations with hypsographical information.

ERRONEOUS DATA INSPECTION AND VERIFICATION

It is the common concern for the DEM data analysts and/or users to know: what is the criteria to determine the erroneous data? where it falls? and how to locate and report it?

To avoid the complex analysis which may require tremendous computational efforts, the Topographical Survey Division has developed the following techniques as part of the DEM inspection/scanning.

Patch-Tie Map

In the process of conversing and transferring the GPM NOVA 800 tape to the in-house PDP 11/70 disk file (Allam, et al, 1980), a patch-tie map as shown in Figure 1 is generated. This is an index listing of the height differences between each patch corner and the mean height of that corner. To avoid printing large numbers, a scaling factor is used, and only absolute integer values between 0 to 9 are printed.

Photographic Contour Overlay and Patch Grid Overlay

A photographic contour overlay is interpolated (on a per patch basis) from the scanned and correlated DEM, and the derived contours are photographically exposed on the GPM contour printer. The patch grid overlay is a transparency with a printed grid, where the spacing between the grid lines are equal to the GPM printing mask dimensions.

By visual inspection of these two overlays on a light table (Figure 2), poorly correlated areas (e.g. isolated contours on the water surface, mis-matched contours between the patches) are easily identified. Further, if only a part of a patch is in error (an edge or corner), its relative location is also determined.

MAP UNIT = 10.   ----- COLUMN ----

ROW	RMS	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8
14		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
14		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	1.9																		
13		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
13		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	2.2																		
12		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
12		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	2.0																		
11		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
11		00	00	10	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	5.8																		
10		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
10		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	2.8																		
9		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
9		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	3.9																		
8		10	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
8		00	06	52	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	12.1																		
7		00	07	40	10	00	00	00	00	00	00	00	00	00	00	00	00	00	00
7		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	2.3																		
6		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
6		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	2.0																		
5		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
5		00	00	00	00	00	00	00	00	00	00	10	00	00	00	00	00	00	00
	2.6																		
4		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
4		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	2.8																		
3		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
3		10	12	00	00	00	00	20	00	00	00	00	00	00	00	00	00	00	00
	6.0																		
2		01	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2		00	00	00	10	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	2.8																		
1		00	00	00	10	00	00	00	00	00	00	00	00	00	00	00	00	00	00
1		00	00	03	30	20	00	00	00	00	00	00	00	00	00	00	00	01	10
ROW	RMS	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8

MAP UNIT = 10.   ----- COLUMN ----

RMS FOR WHOLE PATCH TIE = 2.9

Figure 1. Patch Tie Map

Patch Edges Linkage Display

A closer examination of the doubtful patch elevations is made by displaying the data on a video terminal (Figure 3). It shows the elevations along the edges as well as the data of the patch adjacent to it. From the selective profiles, along x-axis or along y-axis, it indicates the general trend surface of the current patch.

DEM INTERACTIVE EDITING

Upon completion of the DEM inspection phase by the operator, the process of DEM editing and filtering is performed by a software system. The software was designed and developed to allow for a controlled interactive editing of DEM data. For this purpose, a video terminal is required for the I/O program operations (see flow chart in Figure 4). Also a graphic display terminal (TEKTRONIX 4015) and a digitizer (TEKTRONIX 4953 graphic tablets) are required to edit a polygon (see figure 5)

The following interactive editing options are available:

Replace a Point with a Known Elevation

If the height value of a terrain point is known, e.g. a ground control point, the corresponding DEM point is replaced.

Replace the Entire Patch with a Known Elevation

If the patch is located over a body of water, e.g. lake with known elevation, the GPM recorded elevations are replaced.

Z-Shift of Entire Patch

In forest areas, if the average height of the trees is known, then the topographic surface of the area could be obtained by applying such Z-shift to the DEM.

Delete Entire Patch Data

If the patch is located in the edge or corner of the model, false elevations may be generated and this patch is usually discarded.

Tilt One Corner of a Patch

Occasionally, some patches lack a good correlation, particularly in the corner area, and it is necessary to edit a patch segment to achieve homogenity in elevations with other patches.

A patch is divided into nine sub-blocks as shown on Figure 3. The poorly correlated corner can be identified easily through the analysis with the help of the values of the adjacent points of neighboring patches.

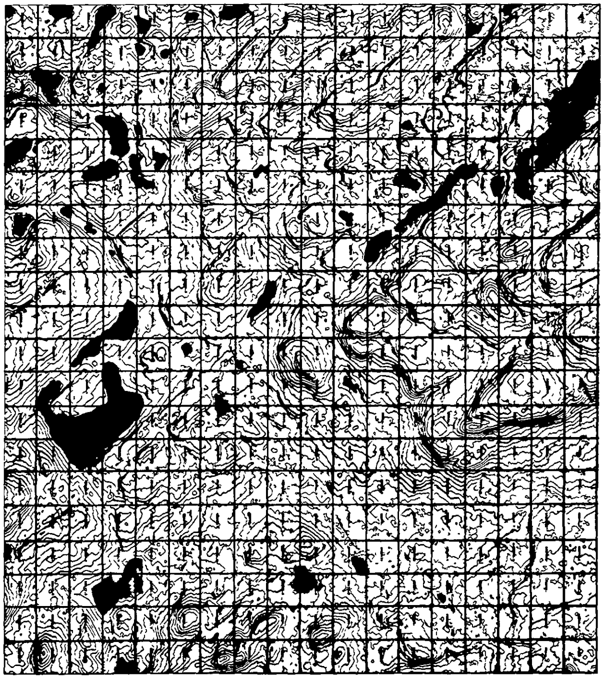

Figure 2. Photographic Contour Overlay and Patch Grid Overlay

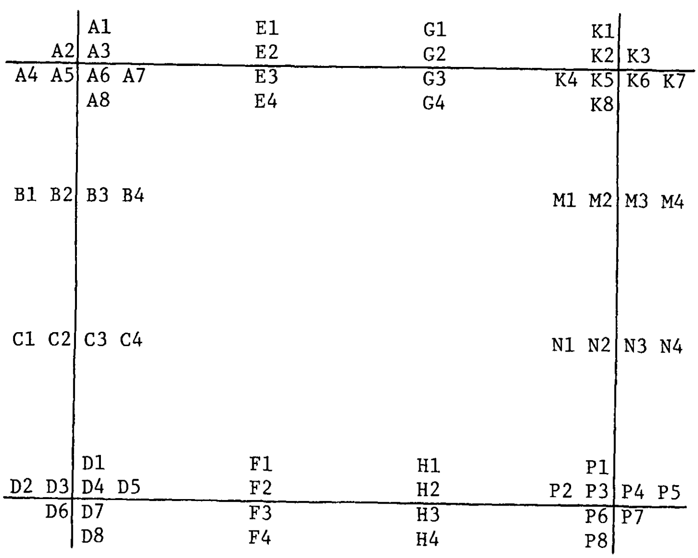

Figure 3. Patch Edges Linkage Display

Assuming S-W corner of the patch has to be tilted due to mis-match of point "D4" with its neighboring points (D3, D6 and D7) in the adjacent patches, and assuming also the profiles C1 to C4 and F1 to F4 are satisfactory, a new elevation R(1,1) for point D4 is interpolated from the acceptable neighboring corners (D3, D6 and D7). New elevations R(i,j) in this sub-block are computed as follows:

For $i = 2$ to $q-1$, and $j = 1$

$$R(i,j) = R(1,1) + (i-1)\,[Z(q,1) - R(1,1)]/(q-1)$$

For $j = 2$ to $q-1$, and $i = 1$

$$R(1,j) = R(1,1) + (j-1)[Z(1,q) - R(1,1)]/(q-1)$$

For $i = 2$ to $q-1$, and $j = 2$ to $q-1$

$$R(i,j) = [R(i,1)S1 + Z(i,q)S2 + R(i,j)S3 + Z(q,j)S4]/S$$

where

$S1 = 1/(j-1)^2$, n = mask size,
$S2 = 1/(q-i)^2$, $q = 2(n+1)/3$,
$S3 = 1/(i-1)^2$,
$S4 = 1/(q-1)^2$, and
$S = S1 + S2 + S3 + S4$.

If necessary, similar process may be used to modify the Z-values of the other patch corners.

Smoothing of the Linkage of the Adjacent Patches

Due to prior correlation, the Z-values of the patch may represent its topographical characteristics to a certain degree, but these Z-values do not fit to their adjacent patches. Therefore, a Z-adjustment of the patch is needed, and the edge elevations of neighboring patches are used as control values.

The general formula for the trhee-dimensional linear conformal transformation used is:

$$E = \lambda AX + C$$

in which:

E is a column vector with the control values of x-, y- and z-coordinates of a point as components,

X is a column vector with the transformed values of x-, y- and z-coordinates of a point as components,

λ is a scale factor,

A is an orthogonal matrix that represents a rotation in three-dimensional space, and

C is a column vector with X-, Y- and Z-shifts as components.

The minimum prerequisites for control configuration for this conformal transformation are selected (four points per edge) as follows:

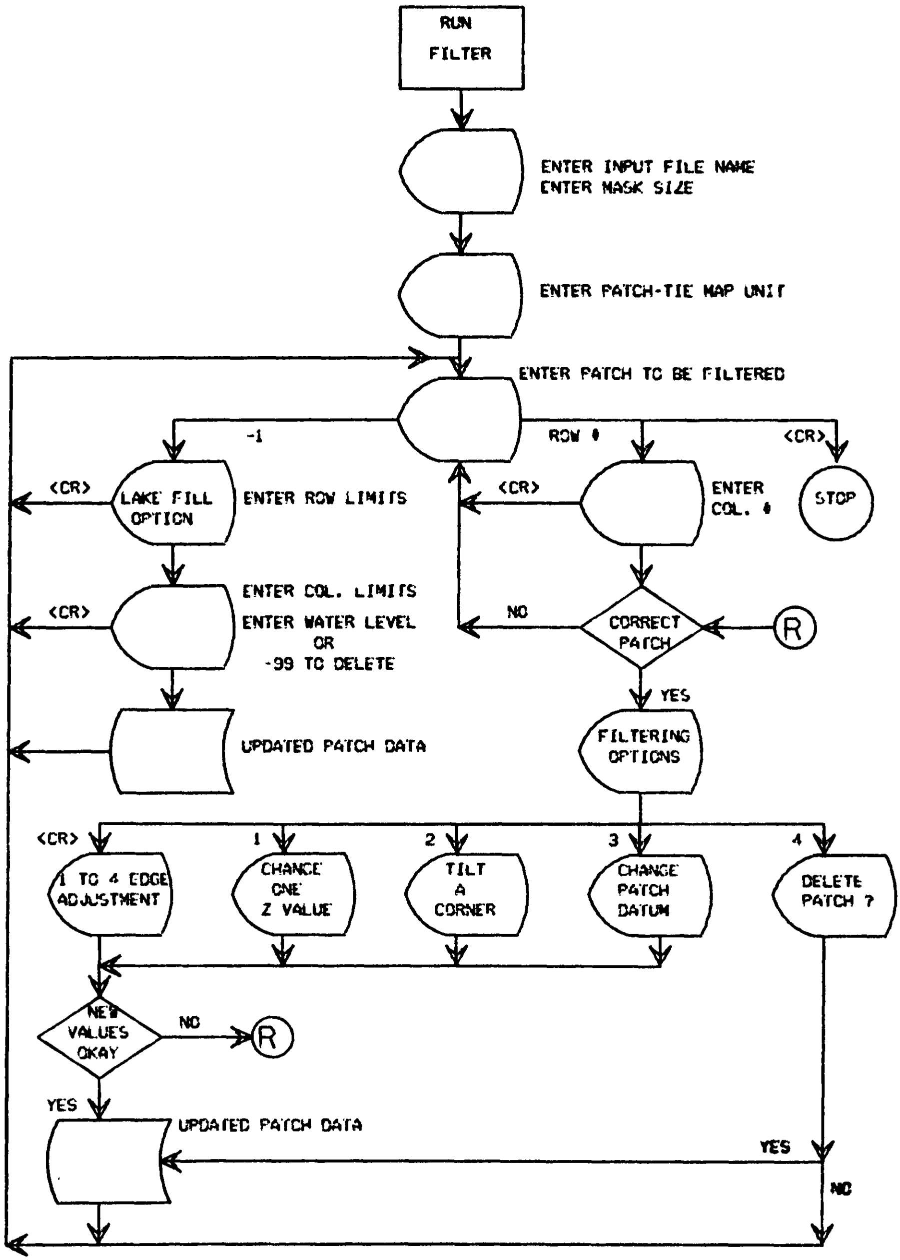

FIGURE 4. OPERATIONAL FLOW CHART OF PROGRAM FILTER

(a) points on two parallel edges indicating a fit to its neighboring patches,
(b) points on two perpendicular edges in the patch indicating a fit, and an auxiliary point at the intersection of the two other edges.

Editing the DEM of a Polygon (Program WAF)

The polygon encompassing poorly correlated areas (e.g. lakes) are digitized from the photographic contour overlay produced by the GPM using TEKTRONIX 4953 Tablet. These X,Y values are expressed in the local coordinate system of the patch matrix. The elevation within this polygon are determined based on terrain coverage and/or external height informations. For example, if the polygon contains a water surface, the elevation is obtained as the mean elevation of all points on the perimeter, or the elevation is known from a map manuscript, hydrographic gauge, or a photogrammetric process. In the case of forest coverage with a known average tree height, a Z-shift is applied within the forest polygon.

This editing process is performed interactively using program WAF, as shown in Figure 5.

DEM STANDARDIZATION

The DEM's produced from the photogrammetric models using the GPM have various elevation grid spacing and orientation based on input imagery. To the DEM users, this diversity may be an obstacle in creating the contours and in selecting terrain elevations from different models on the overlapping area. Therefore, the concept of the global grid elevations, positioned horizontally with the UTM coordinate system, was developed in Topographical Surveys Directorate (Allam, Wong 1976).

Global Grid Elevations (Model)

The DEM is divided into square cells parallel to the UTM coordinate system; each cell has a 10 X 10 grid matrix with a constant grid spacing. The elevation of each grid intersection (node) is interpolated from the DEM patch data by constructing a surface whose weighted sum of the squares of distances to the reference patch points is a minimum (Allam, 1978). The formation of the global grid elevation yields the following advantages:

- produces a uniform digital terrain elevation grid,
- smoothing of the topographic surface,
- provides a means to reduce the quantity and keep the quality of the massive data oriented DEM file.

Global Grid Elevations (Map Sheet)

A global grid elevation in map sheet form is created in order to construct a uniform grid of elevations over a map sheet area, eliminate the problem of matching the model edges, reduce the quantity of elevation data on the model overlapping area, and to provide a better elevation data base in contouring (Allam, Low, 1980).

All global grid elevation (models) in the map sheet area are merged, and mean elevations are computed between the overlapping cells.

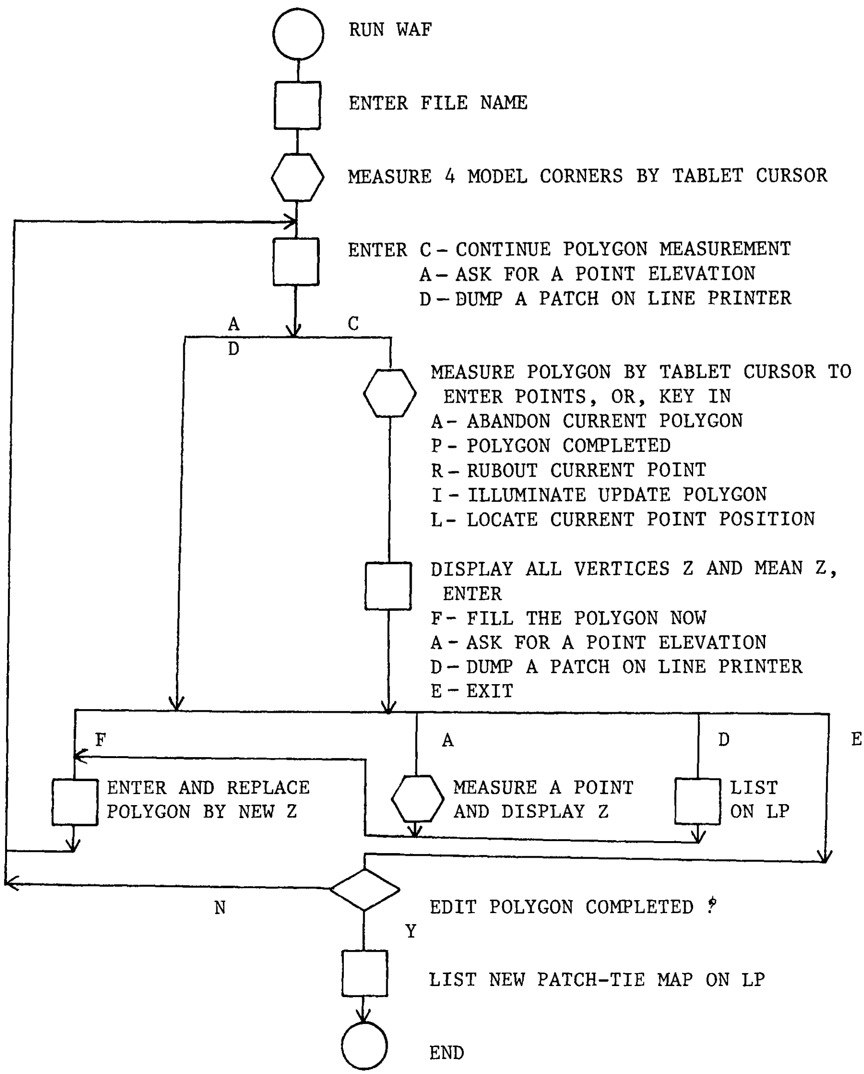

Figure 5. Operational Flowchart of Program WAF

REFINEMENT OF GLOBAL GRID ELEVATION WITH HYPSOGRAPHIC DATA

Upon completion of the process of constructing a global grid of elevations per map, the contouring program may be used to interpolate for a graphic contour overlay. In practice, there is a problem of generating cartographically acceptable stream re-entrants with the generated contours. To solve this contour/ drainage problem, usually time-consuming on-line interactive graphic editing or manual processes were used. To improve the efficiency of this process, a batch mode program (SRE) was developed.

Positional coordinates of the stream are digitized from an orthophoto or by a photogrammetric process as shown in Figure 6. Program (SRE) computes the weighted arithmatic mean of the nodal points (e.g. A,B) from the closes four grid elevations, and the elevations of the digitized stream points (1,2,...n) on the grid profile are computed with the linear slope interpolation formula:

$$Z_i = (Z_A + Z_B - Z_A) \cdot d_i/S$$

where

Z_i = elevation of points i, i = 1, ... n,

S = distance between A and B,

d_i = distance between point i and point A,

Z_A, Z_B = elevation of point A and point B.

The grid elevations in the shaded area (2 grid spacing width) along the stream can then be re-defined as follows:

Take point j as example:

$$Z_j = \tfrac{1}{2}[Z_5 + \frac{S_{5-j}}{S_{5-D}} \cdot (Z_D - Z_5) + Z_6 + \frac{S_{6-j}}{S_{6-C}} \cdot (Z_C - Z_6)]$$

where

Z_j = re-defined elevation of point j,

Z_C, Z_D = elevations in DEM file,

Z_5, Z_6 = elevations along the stream, defined by eq.,

S = distance between two points,

To illustrate the advantage of using this method, Figures 7a and 7b show a contour overlay before and after using the program SRE.

CONTOURING AND INTERACTIVE CARTOGRAPHICAL EDITING

Linear interpolation method is used on the global grid elevations (map sheet) to produce graphic contours (Allam, Low, 1980). Since the output contour file is in the same format as that used in Interactive Graphic Design System (IGDS), further graphic editing is feasible.

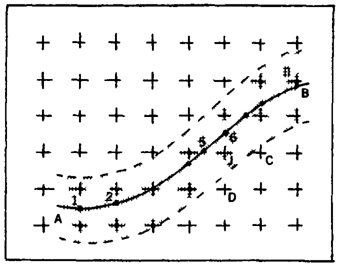

Figure 6. Segment of a Digitized Stream

CONCLUSION

Refinement of the dense DEM is essential to maintain a high quality digital elevation data base and digital topographic products. Interactive editing procedures to verify and filter the erroneous elevations is effective, particularly in a time-sharing, mini-computer processing environment. Standardization of the DEM's with the global grid concept broadens its application and leads to an automatic contouring phase. Natural topographic features, such as hypsographic information, have to be considered for the refinement of the dense DEM.

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3. Allam, M.M., and B.A. Low, "Software Package for the Contouring of Massive DEM in a Mini-Computer Environment", 14th ISP Congress, 1980, Volume XXIII, Part B3, Hamburg, PP. 19-25.

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5. Zarzycki, J.M., "An Intergrated Digital Mapping System", The Canadian Surveyor, Volum 32, No. 4, December 1978, PP. 443-453.

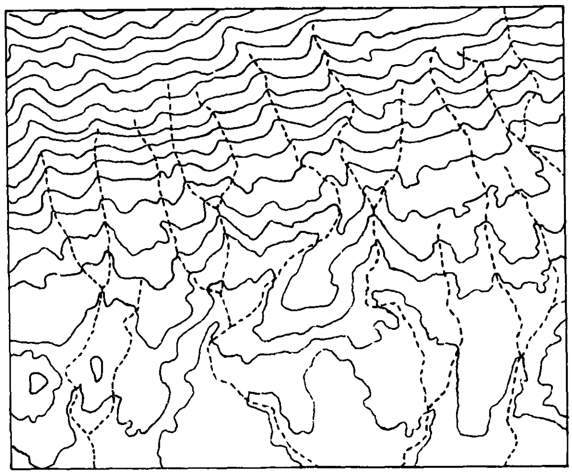

FIGURE 7a. DERIVED CONTOUR OVERLAY
BEFORE "SRE" EDITING

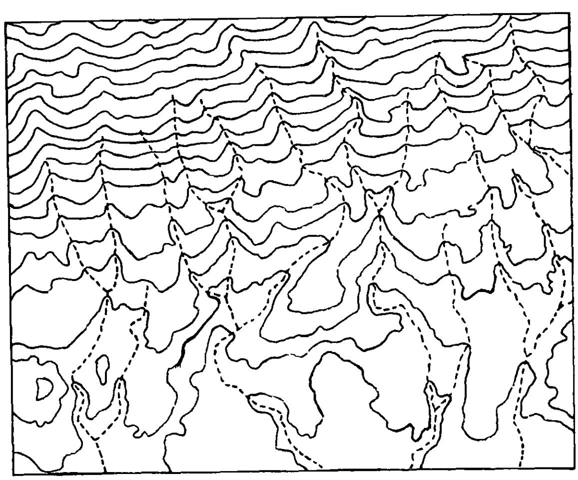

FIGURE 7b. DERIVED CONTOUR OVERLAY
AFTER "SRE" EDITING

AN EVALUATION OF THE NOAA POLAR-ORBITER AS A TOOL FOR MAPPING FREEZE DAMAGE IN FLORIDA DURING JANUARY 1982

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INTRODUCTION

Approximately two thirds of the nation's citrus crops are grown in the state of Florida. In addition, Florida is the major producer of vegetables on the east coast. Occasionally, below freezing temperatures will cause extensive damage to these crops. In January of 1981 and again in 1982 extreme cold temperatures resulted in widespread damage to these crops. The extent of the damage was assessed and documented by the Statistical Reporting Service, United States Department of Agriculture. Previous research on the use of Landsat and Meteorological (Metsat) Satellite data has indicated that crop vigor - "greenness" can be detected in the visual and near-infrared wavelengths. The purpose of this study was to determine if damaged citrus and vegetable crops could have been detected immediately after the January 1982 freeze wtih the use of the NOAA-7 Satellite data.

TECHNICAL DISCUSSION

The NOAA-n series meteorological satellites are polar orbiting and the on-board Advanced Very High Resolution Radiometer (AVHRR) collects data for Channels: 1, 580-680 nm; 2, 725-1100 nm; 3, 3550-3930 nm; 4, 10500-11500 nm, and if so engineered, Channel 5, 11500-12500 nm. These data are collected for any given location of the world at least once each day. The pixel size of the AVHRR data is approximately (1 Km) . Channels 1 and 2 have been used to detect greenness and changes in greenness over short periods. The data selected for this experiment were closen from the daily coverage to have few or no clouds and immediately after a cold frontage passage. Such criteria provide near minimum atmoshperic effects upon the reflected solar radiation. Thus, changes over an area, from one period to another, would be mostly attributed to the actual changes in the "greenness" of the plants.

Registration of the Metsat data has not been perfected, therefore a pixel to pixel comparison on a day to day basis is not possible. For this study it was decided to minimize the registration problems by a rectilinear system of I-J grids. This grid system circumscribes a polar stereographic projection of a hemisphere of the earth. Each square (grid) identified by a column (I), row (J) can be explicitly located on the earth as long as it is inside the equatorial circle.

Using this system, each pixel of satellite data was allocated in a specific I.J. grid. The percent of pixels from one land use category to the total number of pixels in the grid was used as areal coverage. It is known that some error will exist in this method for each I-J grid, when compared from one day to another. But using several grids together would minimize the error. For the grid which covers part of Tampa Bay, the percent of water for the three dates ranged from 19.525% to 21.865%. This would result in an error of about 4.62 square miles out of 625 sq. mi. (one grid).

The pixel data for each grid was processed using a look-up table. This table uses Channel 1 versus Channel 2 and was set up to detect the greenness, nearly bare soils, clouds and water. The values used for classification were arrived at from experience with the GMI (Gray, McCrary Index) which is the difference between Channel 2 and Channel 1 data. Different values of the GMI reflect the degree of greenness.

Changes in the percent of greenness values for the central portion of Florida were determined for three periods. A larger area of the state would have been evaluated but the non-availability of satellite data precluded it. Three dates were used, one just before the freeze, (9 January), one about a week after (16 January), and then the third (26 January) about two weeks after the freeze.

DATA

NOAA-7 satellite data was requested for the above three dates. They were found to be favorable with regard to clouds and location of the satellite with relation of Florida. Total coverage of Florida was desired but only the central portion was common on all three data sets. The satellite data was ordered from Satellite Data Service Division (EDIS/NOAA). Currently, it is difficult to obtain Metsat data once it has been placed in the archives. This is due to equipment and storage problems but funding is not available to alleviate these conditions. The processing of the data was done on a PDP/11 computer at the Department of Aerospace Engineering and Engineering Mechanics of the University of Texas at Austin, Texas. The software was developed by the AgRISTARS Early Warning/Crop Conditions Assessment Project.

Ground truth data was obtained from U.S. Dept. of Agriculture, Statistical Reporting Service. It included a Vegetable Summary of 1980, Citrus Summary - 1981, freeze damage assessments, and Florida citrus forecast.

The raw digital satellite data (Channels 1-2) were first allocated to a grid location, then the allocated raw data for Channels 1 and 2 were processed by a classifier (Fig. 1) and printed on a dot matrix printer. The printer plots were then fitted together, forming a map of Florida. The water, clouds and "greenness" were analyzed for changes with time.

DATA ANALYSIS

The changes in greenness were plotted for four grid values that corresponds to the location of counties with heavy production of citrus fruit. These counties each produced more than 10,000 boxes of citrus in the 1980-81 season. (Fig. 2). Some cloudiness was present on the January 16 date which had a major affect on the grid values. High readings of Channel 1 were labeled with a negative index (2-1) as clouds.

The minimum temperatures that were observed on the morning of January 12, 1982 averaged 22°F but ranged between 26° and 16°F. Temperatures at or below 26°F were sustained for about 10 hours. The shortest was seven hours and the longest was 12 hours (Fig. 3). This freeze was very similar to the freeze that occured on January 14, 1981. The January weekly Weather and Crop Bulletins published by NOAA/USDA Joint Agricultural Weather Facility reported the following:

- o That 84 percent of the oranges sampled had internal ice.
- o The extent of the damage to fruit resulting in lost production could not be directly inferred by their survey icing percentages.
- o Cold weather since mid-November placed trees in good condition to withstand the cold.
- o However, unseasonably warm weather during the last two weeks had begun to bring out some new growth. The condition of foliage indicates severe wilt and burning, with some defoliation likely.

This new growth was severly damaged by the freeze. Florida Weather and Crop News, dated January 18, 1982, reported that there was considerable leaf curl on the citrus trees, and in early Februry the USDA projected a decrease of about

20 percent in citrus production as a result of the freeze. The classifier shows the percent of total pixels in each classification category. (Fig. 4) is a plot of these percentages plotted for each of the three days, January 9, 16 and 26. An index number of eight is highest with greenness decreasing with index values.

The percentage of pixels in each of the categories against the total pixels was plotted for each of the three days, January 9, 16 and 26. This plot reveals few readings as high as an eight. Most of the values were sixes and fours.

Values of six for four counties which are very high producers of citrus were examined. About 50 percent of the total area had readings of 6. This was reduced to about 25 percent immediately after the freeze. This would represent about one fourth of the area. The values for about two weeks after the freeze shows a rapid increas in index values to about 40 percent with readings to 6 again.

In addition to the counties that were mostly citrus producers, two grids that cover major vegetable producing counties were analyzed. The higher index of 8 or above represented about 18 to 20 percent of the total area. The values of 6 about 60 percent of the total pixels. After the freeze the number of pixels with readings of 8 and 6 fell sharply. The data analyzed two weeks after the freeze displayed almost no recovery in the 8 or 6 greenness categories on one grid. The other grid displayed a partial recovery. The difference in recovery was because the area was mixed citrus and vegetables.

CONCLUSION

The NOAA-n Satellite is capable of detecting changes in greenness that occur over short periods of time and an estimation of the area of damage can be made. The severity of the damage was not evaluated in this experiment.

Very frequent coverage by satellite is necessary to obtain short period changes in greenness. With daily coverage it would be possible to monitor changes of less than one week in most instances.

Resolution afforded by the NOAA-n Satellites is sufficient to monitor changes in areas as small as the I.J. grid. Changes in smaller areas such as moderate size lakes, large fields and large rivers could also be detected.

CLASSIFICATION TABLE

```
. . . . . . . . . . . . . . . . . . . . . . . .  . ++$  . .  . .
. . . . . . . . . . . . . . . . . . . . . .    , ++$. .  . . .
.  . . . . . . . . . .  . .  . . . . . . . +++$$  . . . . .
. . . . . . .  . . . . . .     .  . . ++++$$  .    . . .
. . . . .  . . . . . . . . . ==++++$$  .  .    . . . .
. . . .  . . .  . . . . . .  ===+++$$  . . . . .  . . . .
----------------===+++$-------------
---------------===+++$--------------
-------------&&&+++$----------------
-----------&&&&++++-----------------
---------&&&&&++++4466880022355577991
-------&&&&&++++44668800223555779911#
XXXX&&&&++++44668800223555779911##>
XXXXX&&&++++44668800223555779911##>>
XXXXX&&&+++44668800223555779911##>>>
XXXXX&&+++44668800223555779911##>>>>
XXXXX&+++44668800223555779911##>>>>>
XXXXXX++44668800223555779911##>>>>>>
XXXXX++44668800223555779911##>>>>>>>
XXXX+++44668800223555779911##>>>>>>>
XXX+++44668800223555779911##>>>>>>>>
XX+++44668800223555779911##>>>>>>>>>
ZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZ
```

X Water
\+ Wet soil
= Shallow water or wet soil
\> Highest GMI
\# Very high GMI
4 GMI = 4
6 GMI = 6
8 GMI = 8
0 GMI = 10
2 GMI = 12
3 GMI = 13
5 GMI = 15
7 GMI = 17
9 GMI = 19
1 GMI = 21
· Cloudy
\- Partly cloudy
$ Sand
& Dirty water or flood water
Z Shadow or very dark area

Figure 1

DISTRIBUTION OF PRODUCTION
BY COUNTIES, 1980-81

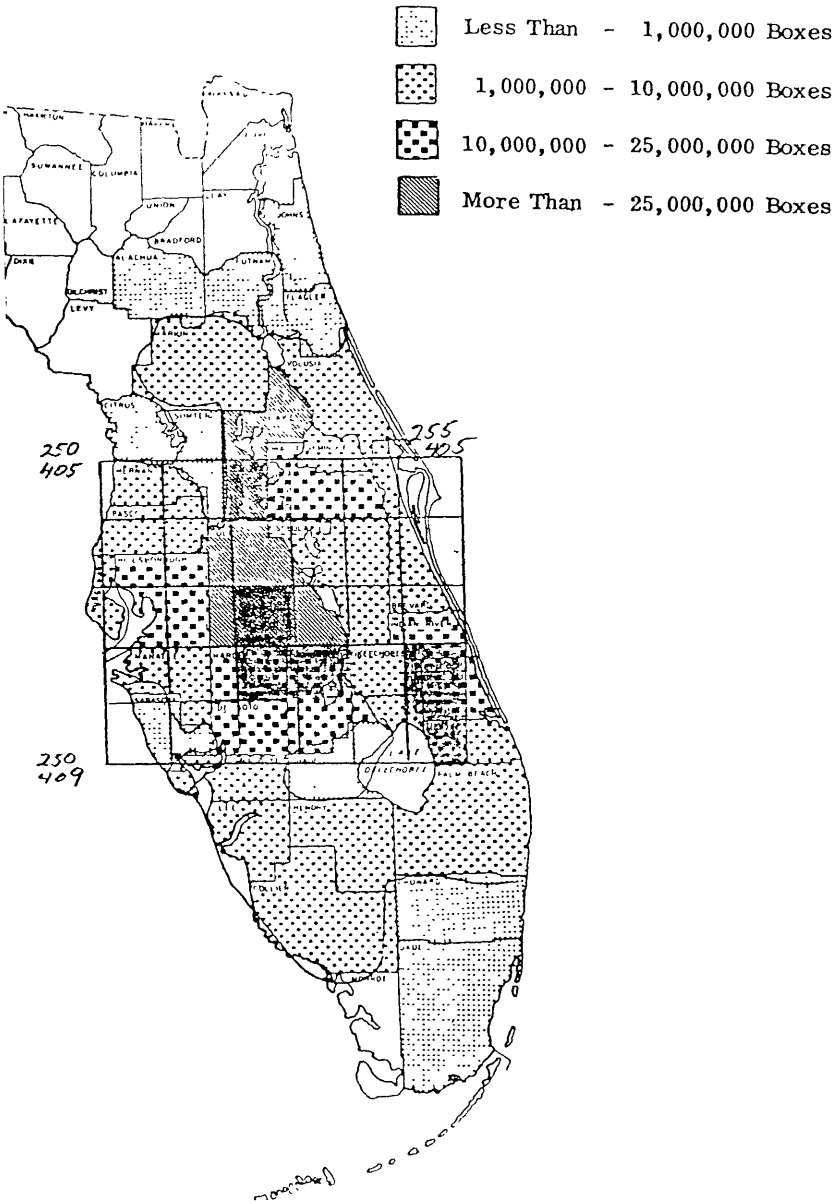

Figure 2

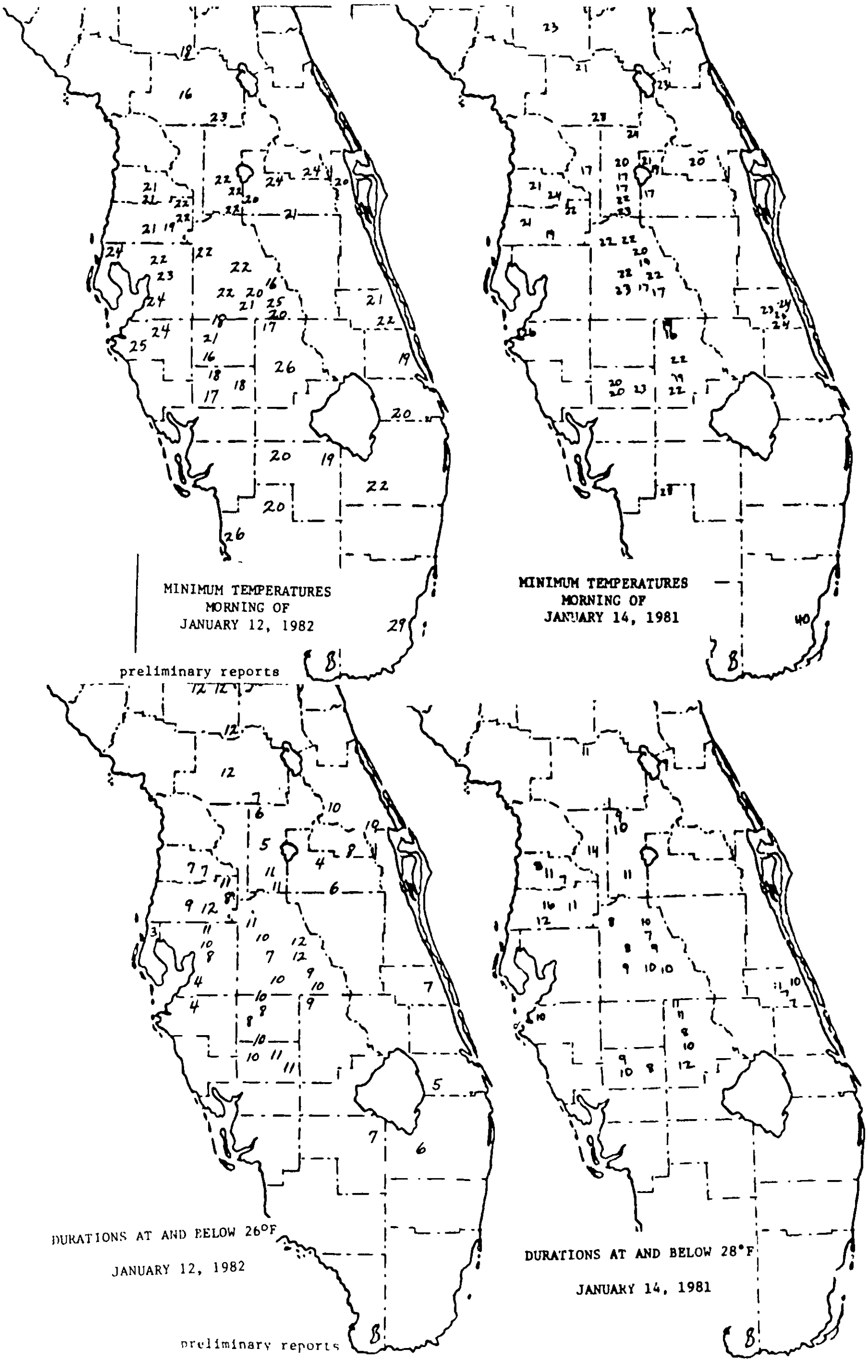
MINIMUM TEMPERATURES
MORNING OF
JANUARY 12, 1982
preliminary reports
MINIMUM TEMPERATURES
MORNING OF
JANUARY 14, 1981
DURATIONS AT AND BELOW 26°F
JANUARY 12, 1982
preliminary reports
DURATIONS AT AND BELOW 28°F
JANUARY 14, 1981

Figure 3

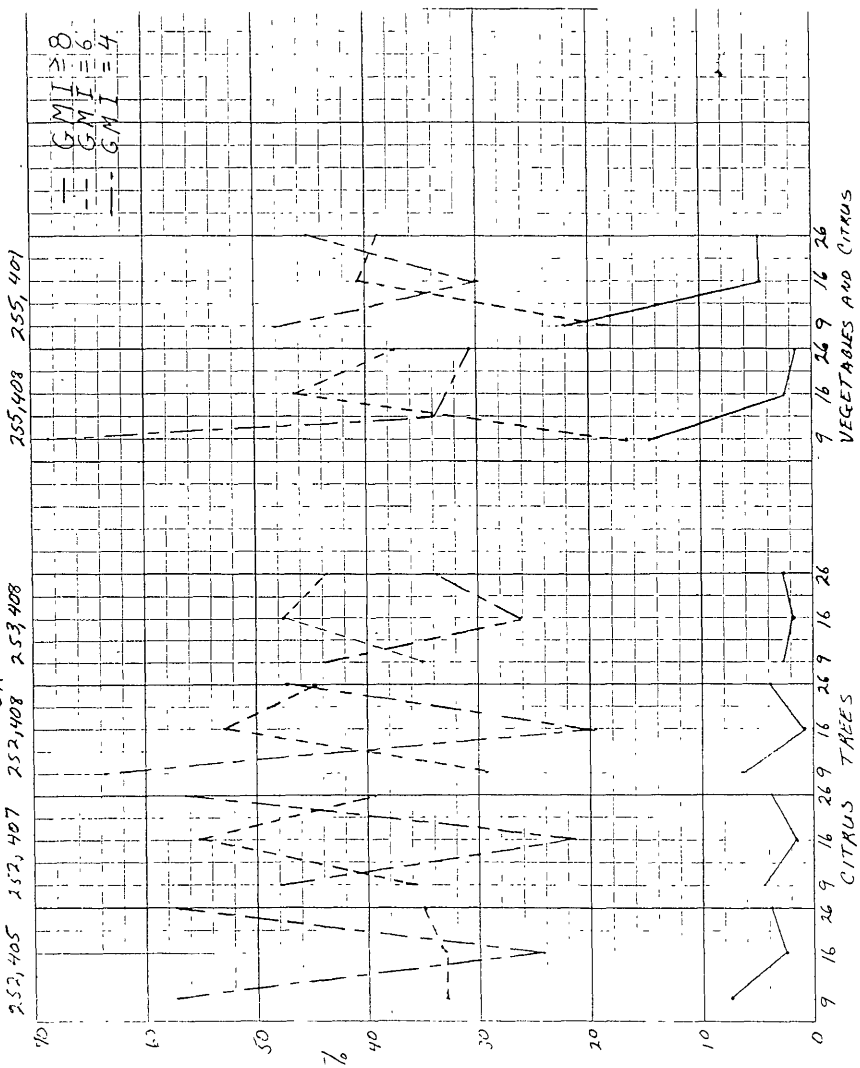
GMI ≥ 8
GMI = 6
GMI = 4
GRID
252,405
252,407
252,408
253,408
GRID
255,408
255,401
CITRUS TREES
VEGETABLES AND CITRUS
%

Figure 4

LAND USE MAPPING AND TRACKING

WITH A

NEW NOAA-7 SATELLITE PRODUCT

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INTRODUCTION

The daily products, Globally Monitored vegetation Index, operationally produced by National Earth Satellite and Data Information Service, NOAA are analyzed for maxima within each seven day period from May through July 1982. The maxima are related to known land uses over North America to develop a use classification system. Weekly variations over active cropped areas are related to vigor of the crops and growth stages. The analysis techniques usually provide global maps of agricultural areas over which most of the transient meteorological effects have disappeared meaning that near absence of clouds and minimum atmospheric attenuation exist.

BACKGROUND

With the advent of the U.S. satellite age, weather surveilence became a primary task resulting in the organization of an operational activity (now NESDIS) to collect and use satellite instrumental data for preparation of timely products. These products did and do support the weather services in the United States and elsewhere about the earth. The earlier products were reconstructed scenes of videcon signals. Each product generation, while addressing its current tasks, needed improvements. Thus each family of instruments fostered development of newer families. One of the latest operational instruments is the Advanced Very High Resolution Radiometer (AVHRR) which has been designed to acquire radiometric information remotely and transmit such data back to earth. Its capabilities include three resolution rates and three transmission modes to diseminate data from five (or four) selected radiometric bandpass channels. It has been designed to provide total global areal coverage once daily by sunlight and once during the night period. Before its final integration with the satellite vehicle, the definition of the bandpass limits for each channel must be set. For the TIROS-N unit, channel 1 was defined to span 500 n.m. through 1100 n.m; channel 2, 680 to 1200 n.m.; channel 3, 3550 to 3930 n.m.;

and channel 4, 10500 to 11500 n.m. (all limits approximate). Then for the succeeding vehicles, NOAA-n's new definitions were established for channel 1, 550 to 700 n.m. and channel 2, 690 to 1050 n.m. Those for NOAA-7 are channel 1, 550 to 690 n.m. and for channel 2 710 to 1000 n.m., plus the addition of channel 5, 11500 to 12500 n.m.

These reflective wavelenghts of channel 1 and channel 2, onboard NOAA 6 & 7, were selected by hydrologists for the purpose of identifying melting snow; but too late to be included on the TIROS-N AVHRR. (Schneider, 1977) Fortunately, these chosen channels in the reflective solar spectrum are nearly optimized for detection of vegetation. Gray and McCrary (1981a) demonstrated this capability by comparing their vegetation index (later named the Gray McCrary Index - GMI) with the Landsat data-based Ashburn Index. Subsequent investigations by Perry and Lautenschlager (1982) have verified these findings. Then Gray and McCrary (1981b) showed the response of the GMI could track the health, or lack thereof, of vegetation, define water surfaces and detect cloudiness. Accordingly, they recommended in late 1980 that NESS develop a new product - the daily vegetation global map and a weekly "best value" vegetation index composite map.

PRODUCT DESIGN

NESS had had the experience of producing weekly snow maps based upon the "minimum Brightness" weekly composite mapping - basically, mapping daily brightness as observed by the satellite each day for a week, then saving only the lowest brightness at each of the grid locations. Beginning in April 1982, the vegetation index mapping procedure was begun; consisting of daily gridded data being produced and then a seven day series are surveyed to extract the "best" vegetation index for each grid point which are recompiled into a "best" composite map. This new product was developed through cooperation between the Applications Laboratory and Special Products Division of National Earth Satellite Services and the Satellite Data Services Division of the Environmental Data and Information Services. A report is to be published (Tarpley, 1982). Supporting evidence for this technique is illustrated by the spectral curves shown in Figure 1 and in the NOAA-7 Channel 2 & 1 computed responses listed in Table 1.

TABLE 1

Assumed Surface	% Reflectance		Indices (2-1)	(2-1)/2+1	2/1
Vegetation Types:	Ch 2	Ch 1	GMI	NVI	Ratio
Well-watered wheat	19.66	0.83	18.83	.919	23.7
water-stressed wheat	16.65	2.93	13.72	.701	5.7
Alfalfa	14.00	1.64	12.36	.790	8.5
Soybeans	28.27	2.12	26.15	.860	13.3
Diseased Soybeans (11.5%)	13.39	2.82	10.57	.652	4.8
Non-Vegetation:					
Concrete	19.44	15.60	3.84	.110	1.25
Asphalt	7.35	5.11	2.24	.180	1.44
Sand	13.40	8.69	4.89	.221	1.54
Reddish Soil	7.80	8.78	-0.98	-.055	.89
Water	0.01	0.37	-0.36	-.958	.02
Ice/clouds	54.75	79.16	-24.41	-.182	.69

Thus, the "best" response for each given location will be a clear surface, i.e. water, soil, and/or vegetation, provided that location did not present a cloud/ice signature for each of the seven days; and, vegetational signatures would dominate.

DATA ANALYSIS

Analyses consist of several actions: (1) subjective evaluation of photographic/hard copy displays; (2) examination of digital output for comparison with other index techniques; (3) and the production of index changes with time. During the presentation of this paper, color products from the Advanced Graphics Laboratory, University of Texas/Austin are shown for the North American area to illustrate the subjective technique (Fig. 2).

Data for selected periods have been extracted for three given areas over the United States: (1) an area near Chicago, Illinois, (2) the Texas High Plains, and (3) Florida, north of Lake Okeechobee. Three products for each period and each area were acquired from the digital tape products, one of the outputs of the vegetation mapping techniques. These are examined for the purpose of comparing navigation of the NESDIS operational products to that of the U.S. AgRISTARS EW/CCA data base (or how does the indexing of the 1024 by 1024 i,j grid match that of the 512,512 grid) and for the representativeness of the operational index versus those in the U.S. EW/CCA data base.

Several locations on the North American continent are specified on the operational vegetation index product to be compared to the other grid (Table 2).

TABLE 2

Feature	Geographic N		Locations Column 1024 Grid	Row 512 (x10)		Difference Col 3 minus (Col 4)/5
S. Baja CA	22.9	109.8W	348,802	1746	4009	-1.2+0.2
N. Gulf CA	31.5	114.6W	356,745	1785	3726	-1.0-0.2
S. James Bay	51.2	80.0W	513,690	2570	3449	-1.0+0.2
S. L. Mich.	41.6	87.4W	484,737	2426	3683	-1.2+0.4
W. Okeechobee	26.9	18.1W	407,821	2542	4103	-1.2+0.4
S. Florida	25.1	80.6W	409,832	2553	4157	-1.2+0.6

As illustrated in Table 2, the 512 by 512 gridded data base used by the Foreign Agriculture Service, Crop Condition Assessment Division (FAS,CCAD) and the AgRISTARS Early Warning/Crop Condition Assessment (EW/CCA) project, provides a higher i number than the operational Globally Monitored Index (GMI) but the j values are approximately correct. Considering the evaluation procedures used for operational computations of the EVI (environmental vegetation index) in Houston, the four GMI's to be used for a single data base location would consist of these grid locations:

$$I_p = 2I-1 \qquad J_p = 2J$$

$$I_{p-1} = I_p-1 \qquad J_{p+1} = J_p+1,$$

where the subscript p indicates the operational 1024, 1024 grid system and the non subscripted data refer to a location in the 512,512 array.

Analysis of the GMI area values with respect to the data base EVI values consists of paring the sums of the assumed four representative GMI's with EVI's archived in the data base. 147 pairs were correlated for the period of 6-12 July, 1982 (Actually only two data passes, 2 days, existed in the data base for this period; but, the composite did not necessarily select the same days as "best") for a correlation coefficient of .811 (Fig. 3). In scale of values for the GMI, note that 1) the GMI represents the sum of four grid locations, whereas the EVI is a single mean integer value (ranging from 4 through 13 in the sample used; 2) the GMI is computed from the AVHRR raw count data and changed from 10 bit data to 7 bit data while the EVI is computed from albedo values; 3) the GMI value at a given location is the "best" single value of seven days, but the EVI is the mean of about 2000 screened pixels (j and 4) the GMI is the equivalent of skip line and skip pixel sampling of global area coverage (GAC) data (4 km pixel size) and the EVI is computed from all available local area coverage (LAC) data which pass the screening tests.

CONCLUSIONS AND RECOMMENDATIONS

The Globally Monitored Index (GMI) weekly composite charts represent useful data to assess world agriculture to the extent that any other vegetation index is useful. However, variations in the dimensions of various geographical features indicate a need to improve the navigation techniques used to assign AVHRR data to earth locations.

The difference in scalar values of the GMI with respect to the ranges used by FAS/CCAD and EW/CCA in their data base currently represent a problem. Thus, rescaling the GMI - using albedo type values rather than raw count derivations - will improve the acceptability of the product.

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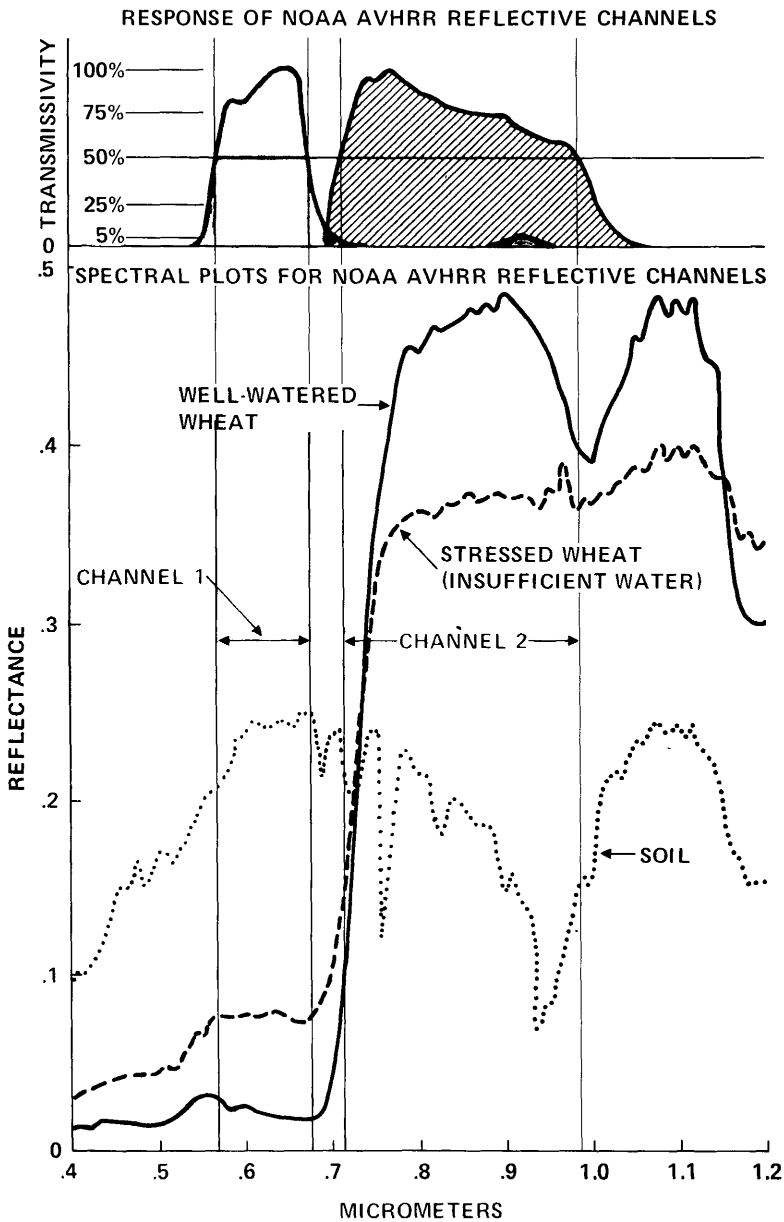

Fig. 1. Part A

Spectral responses of various surfaces and agricultural plants. The curve marked soybeans on righthand graph is that of a diseased planting with 11.8% affected. The upper curves are the response curves of channels 1 and 2 for NOAA-6.

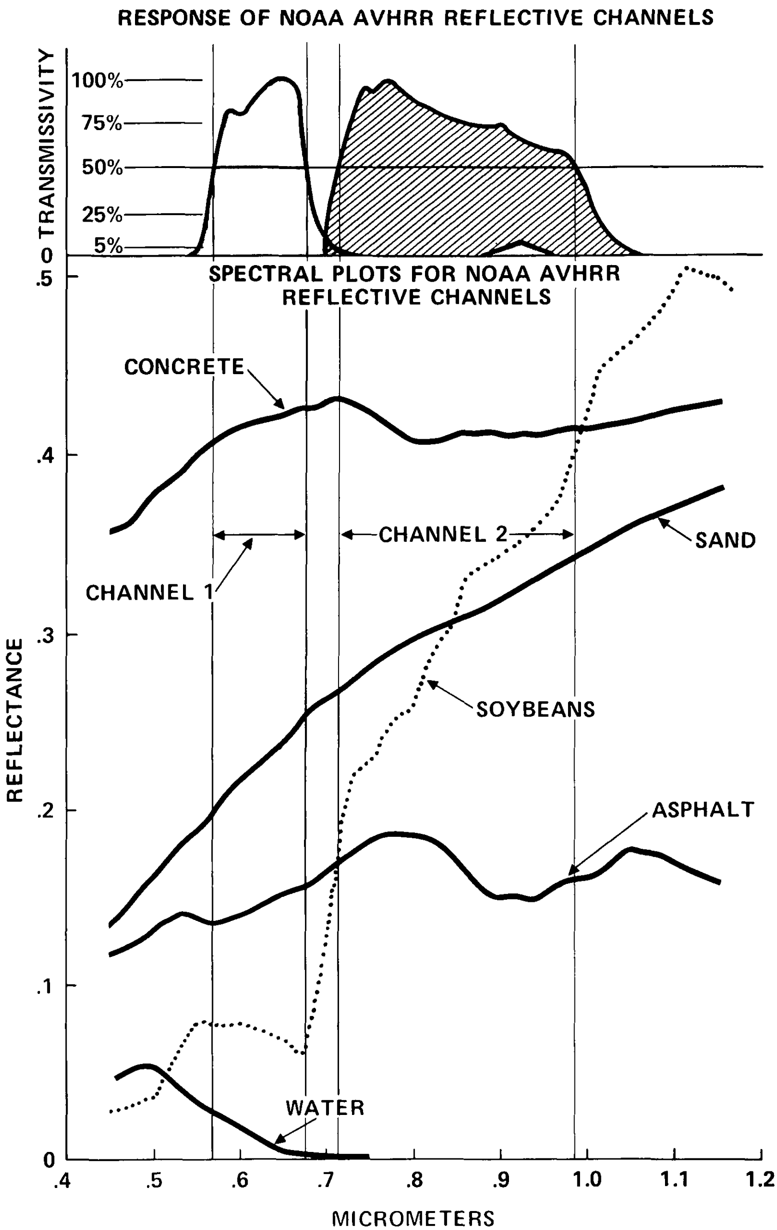
RESPONSE OF NOAA AVHRR REFLECTIVE CHANNELS
TRANSMISSIVITY
100%
75%
50%
25%
5%
0
SPECTRAL PLOTS FOR NOAA AVHRR
REFLECTIVE CHANNELS
CONCRETE
CHANNEL 1
CHANNEL 2
SAND
SOYBEANS
ASPHALT
WATER
REFLECTANCE
.5
.4
.3
.2
.1
0
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
MICROMETERS

Fig. 1
Part B

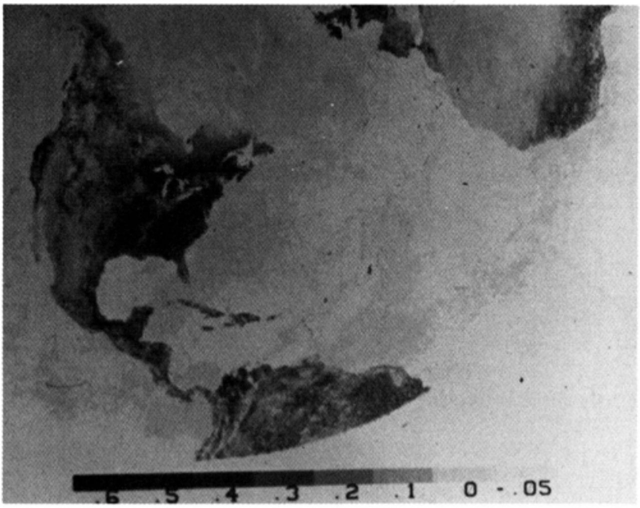

Fig. 2. A portion of the Globally Monitored Indices for North America. The darker the area, the better the "greenness" of the vegetation.

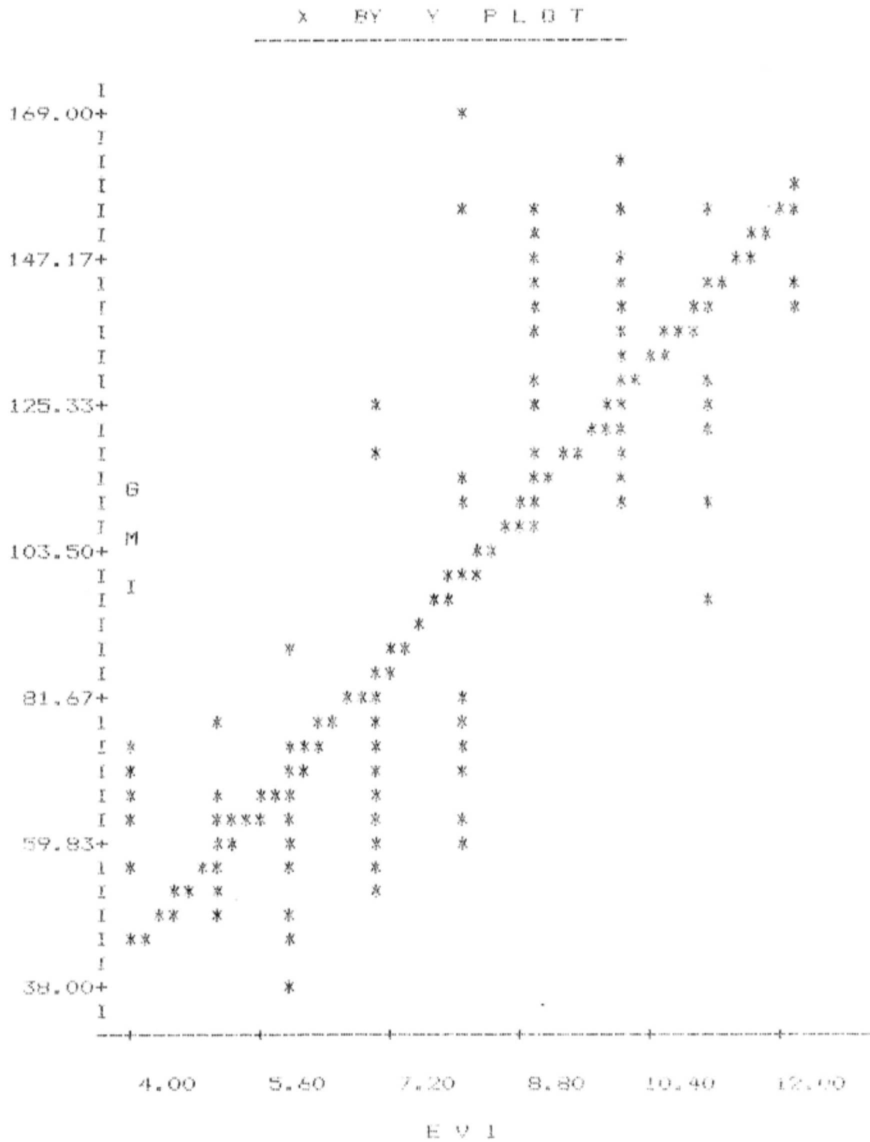

Fig. 3. A plot of the sums of the GMI values (y axis) vs the EVI values for 147 i,j locations during the period of 6 through 12 July 1982. The correlation coefficient is .811.

SPECIFIC FEATURES OF USING LARGE-SCALE MAPPING DATA IN PLANNING CONSTRUCTION AND LAND FARMING

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SUMMARY

New principles to estimate the accuracy of the functions of point coordinates measured on a topographic map are discussed. Particular attention is given to the consideration of the coordinate errors' autocorrelations allowing to obtain original results for the estimation of the accuracy in the determination of farming land areas, distances, slopes, and other data widely used in planning construction and land farming.

USING LARGE-SCALE MAPPING DATA

Topographic maps are used in town designs, land development and rational land use, management of land evaluation cadastre, etc. The reliability of the pertinent decisions depends on the accuracy of positioning the points on the map. It is necessary also to estimate the accuracy of the functions of the points' coordinates (i.e. slopes, elevations, plot areas, etc.) since that is relevant for the reliability of the end results and their possible use in projecting construction and land farming.

In the general case, the problem is to estimate the accuracy of the function

$$u = f\ (l_1,\ l_2,\ \dots,\ l_n), \qquad (1)$$

where l_i $(i = 1,2,\dots,n)$ are the results of some measurements with the mean square deviations σ_{l_1}.

To estimate the accuracy of the function (1), it is possible to make use of the approximate formula

$$\sigma_u^2 = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial l_i} \sigma_{l_i} \right)^2 + \sum_{j>i} \frac{\partial f}{\partial l_i} \frac{\partial f}{\partial l_j} r_{ij} \sigma_{l_i} \sigma_{l_j} \qquad (2)$$

where $\frac{\partial f}{\partial l_i}$ are partial derivatives of the function (1) calculated by the approximate (measured) values of the arguments; $r_{i,j}$ are correlation coefficients of the values l_i, l_j specified in the correlation matrix.

In many publications dealing with the accuracy of the points' coordinates, the second summand of the formula (2) is neglected supposing the correlation (autocorrelation) coefficients are too small to be taken into consideration. More often than not, this can be accounted for by unawareness of the reasons causing the correlation. In consequence, the result is underrating the effect of this factor on the calculation of the accuracy of the sought values.

We have worked out general formulas to estimate the accuracy of topographic points' coordinates. For instance, at a priori accuracy assessment of the elevation calculated on the basis of horizontals, the mean square deviation formula has the form

$$\sigma_h = \sigma_H \sqrt{2(1-r_H)}\ , \tag{3}$$

where σ_H is mean square deviation of the elevations

r_H is correlation coefficient of the elevations equal to

$$r_H = \exp\left(- \frac{0.18}{\sqrt{S_o}} S\right), \tag{4}$$

where S_o is the maximal distance in m between the points of the digital model used for plotting the map;
S is the distance in m between the points in the map.

Calculations [1] show that when $S \leq 1.5\ S_o$ the correlations should not be neglected. The correlations of the coordinate errors should be taken into account when evaluating the accuracy of plot area calculation and when measuring distances by the mapping materials.

The known formula to calculate a plot area by the coordinates of its vertices is

$$2\ P = \sum_{i=1}^{n} x_i\ (y_{i+1} - y_{i-1}), \tag{5}$$

where x_i and y_i are abscissas and ordinates of the plot vertices.

On the basis of (2) we get

$$4\sigma_p^2 = \frac{\sigma_t^2}{2}\sum_{i=1}^{n} C_i^2 + \sigma_t^2 \sum_{j>i} C_i C_{i+j} \sin d_i \rightarrow$$

$$\sin d_{i+j} \times r_{x_i,x_{i+j}} + \sigma_t^2 \sum_{j>i} C_i C_{i+j} \cos d_i \rightarrow$$

$$\cos d_{i+j}\, r_{y_i,y_{i+j}} , \tag{6}$$

where C_i is the diagonal connecting the points (i-1) and (i+1);

d_i is the directional angle of this diagonal in the direction from the point (i-1) to the point i+1);

σ_t is the mean square deviation of the turning point of the contour on the map ($\sigma_{t_1} = \sigma_{t_2} = \ldots = \sigma_{t_n} = \sigma_t$);

r are autocorrelation coefficients.

The summation is taken first for j = 1, then for j = 2 and so on until j = q at which

$$C_{i,i=q} > T,$$

where T is the correlation interval.

For the model of a rectangular land plot with equal sides S and N turning points, assuming

$$r_{x_i,x_{i+j}} = r_{y_i,y_{i+j}} = r_o$$

we get from (6)

$$4\sigma_p^2 = \frac{1}{2}\sigma_t^2\left[(N-4)4S^2 + 8S^2\right] + 4\sigma_t^2 S^2 N r_o. \tag{7}$$

On the basis of [1] it is possible to take for a priori estimations $r_o = 1/2$. Taking this into consideration and bearing (7) in mind we can get

$$\sigma_p = \sigma_t S\sqrt{N-1} \tag{8}$$

Without due regard of the correlation, the formula for the mean square deviation of the plot area in the example has the form

$$\sigma_p' = \frac{\sigma_t S}{\sqrt{2}}\sqrt{N-2}\,. \tag{9}$$

It follows that neglecting the correlation of the contour points' coordinates results in underestimation of the plot area accuracy approximately by [2] times.

Using the formula (2) it is possible to carry out analysis of contours and land plots and draw conclusions on the accuracy of area calculations on the basis of mapping materials.

The problems of distance estimation accuracy measured by region models are of great interest. A detailed discussion of this problem is presented in [2] . We shall only note that neglecting the correlation of the errors in the coordinates of the segments' ends increases the distance estimation error approximately by $\sqrt{2}$ times.

Since analytical solution of the problems to estimate the accuracy of the functions of the points considering the dispersion (correlation) matrix is cumbersome, the method of statistical trials may be used (the Monte-Carlo method).

Computers are applied at that to model the process to produce topographic maps, formation of the contour points' coordinate errors, appearance of the correlations, etc.

For instance, in estimating the accuracy of farming land areas on the maps, a probability model of the plot is produced using the mathematical statistics apparatus. The following factors are taken into consideration:

- -- the farming land area (P)
- -- the coefficient of the plot elongation (K)
- -- the number of the contour turning points (N).

Then the formula (5) is applied to calculate the area of the plot by the specified coordinates x_i^o, y_i^o of the turning points assumed as true. At each modelling step the coordinates x_i and y_i of the contour points are taken from the expressions

$$x_i = x^o_i + \delta x_i ,$$

$$y_i = y^o_i \pm \delta y_i , \qquad (10)$$

where δx_i and δy_i are pseudorandom errors with a specified distribution.

Thus we obtain a series of random area error realizations

$$\delta p_i = P_i - P^o_i . \qquad (11)$$

The number of the realizations δp_i may be as large as desired and depends on the required accuracy of the end result.

A special algorithm for modelling random errors of the contour points' coordinates has been elaborated at the Chair of Geodesy of the Moscow Institute of Land Use Planning Engineers. It is based on generating random errors in the form of a random vector. The components of the vector are presented as sums of the products of some non-random coefficients and independent random errors taking into consideration the correlation moments

$$K_{x_i y_j} = r_{x_i x_u} \sigma_{x_i} \sigma_{x_j} ,$$

$$K_{y_i y_j} = r_{y_i y_j} \sigma_{y_i} \sigma_{y_j} . \qquad (12)$$

The number of realizations was taken 1000.

The analysis of the results has shown that the mean deviation σ_p of the area of the probability model of the plot, considering (12), may be presented as a curve

$$\sigma_p = \alpha P^{\beta} . \qquad (13)$$

The formula (13) with $r_{x_i x_j}$ and $r_{y_i y_j}$ obtained in [2] has the form

$$\sigma_p \doteq 1.4 \, \sigma_t \sqrt{P} , \qquad (14)$$

where σ_t corresponds to that of the formula (6).

In conclusion it should be noted that in order to come to the right decisions in construction or land farming, the customers should have a clear concept about the accuracy of the various obtained data while using the materials of large-scale mapping.

The results of the studies presented in the paper allow for the solution of this problem with a sufficient degree of reliability since they take into account the correlation of the coordinate errors due to the very technological processes of compiling large-scale mapping materials.

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