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The U.S. Army Engineer Topographic Laboratories (USAETL) geographic information systems (GIS) research program seeks to define GIS requirements for operational use in the 1990's and beyond, and to develop advanced GIS processing techniques that will facilitate detailed, near-real-time update and revision and terrain product generation. USAETL has initiated two new work units in the GIS technology base research program. The projects follow an earlier work unit, the Terrain Analyst Work Station (TAWS), which successfully demonstrated micro-computer-based GIS technology in field and Army garrison environments. From evaluations of TAWS demonstrations and development activities, researchers are proposing baseline Army GIS requirements and are working at developing corresponding performance standards. The functional requirements are the framework for the new work units, the Army GIS Evaluation (AGE) and the Soldier-to-GIS Interface Research (S-GIR). AGE is a study to test and evaluation off-the-shelf GIS with respect to meeting current and anticipated Army requirements for the management and manipulation of digital terrain data (DTD). S-GIR is a developmental effort

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AN OVERVIEW OF THE ARMY GIS RESEARCH PROGRAM

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ABSTRACT

The U.S. Army Engineer Topographic Laboratories (USAETL) geographic information systems (GIS) research program seeks to define GIS requirements for operational use in the 1990's and beyond, and to develop advanced GIS processing techniques that will facilitate detailed, near-real-time update and revision and terrain product generation. USAETL has initiated two new work units in the GIS technology base research program. The projects follow an earlier work unit, the Terrain Analyst Work Station (TAWS), which successfully demonstrated microcomputer-based GIS technology in field and Army garrison environments. From evaluations of TAWS demonstrations and development activities, researchers are proposing baseline Army GIS requirements and are working at developing corresponding performance standards. The functional requirements are the framework for the new work units, the Army GIS Evaluation (AGE) and the Soldier-to-GIS Interface Research (S-GIR). AGE is a study to test and evaluate off-the-shelf GIS with respect to meeting current and anticipated Army requirements for the management and manipulation of digital terrain data (DTD). S-GIR is a developmental effort which will study and prepare a dynamic design for a specialized direct manipulation user interface. S-GIR is based on the critical need for a sophisticated and highly interactive user interface for Army GIS applications. S-GIR is intended to assist designers in developing a sophisticated shell or 'front-end' for GIS modules which will be selected (based on AGE study results) for use in a prototype advanced Army GIS.

1. BACKGROUND

The U.S. Army Corps of Engineers - Engineer Topographic Laboratories (USAETL) have utilized geographic information systems (GIS) for the last decade to develop terrain data models and prepare prototype terrain analysis products, to study data structures and exchange formats, and to support the research and development of both hard and softcopy data capture systems. With the advent of small, powerful and low cost microcomputers, researchers were able to bring GIS technology out to the field to determine its applicability in supporting tactical terrain analysis. The Terrain Analyst Work Station (TAWS) was the first such exploratory developmental effort that utilized 32-bit engineering work station technology to host a GIS. TAWS also featured a hardcopy data capture and mensuration subsystem, and ancillary terrain modeling and environmental effects data base systems. Six proof-of-concept TAWS demonstrations from 1984 to 1987 have shown that GIS can successfully support Army planning and tactical operations in field and garrison settings.

Engineering development of the first GIS-based system to be deployed in the field for tactical applications is underway. The system, called the Digital Topographic Support System (DTSS), will be deployed at Division, Corps and Theater echelons. Initial deployment will consist of three systems. Upon successful development and fielding of the first engineering models, up to fifty-five systems may be procured. The DTSS is designed to have a twenty year lifespan, with planned hardware and software upgrades to incorporate technological advances. The DTSS will initially support processing of primarily 1:50,000 scale Tactical Terrain Data (TTD) which will include the corresponding resolution Digital Terrain Elevation Data (DTED).

The DTSS represents the first of probably several GIS-based systems designed to address the specialized tactical and planning mapping support requirements of the engineering, terrain analysis, logistics, intelligence and combat operations functions of the Army. Currently, other Army terrain data users at echelons below Division, in garrison activities and working on other laboratory and system development efforts, are not included in the planned DTSS program. Many of these users are looking for ways to address their immediate and near-term terrain data processing requirements by seeking to implement GIS capabilities. Additionally, some Army terrain units awaiting the early 1990's deployment of DTSS are looking for low cost interim or supplementary off-the-shelf GIS solutions which will familiarize them with the technology and permit them to initiate digital data base creation activities prior to DTSS deployment. USAETL, acting as the Army clearinghouse for GIS technology, has initiated the Army GIS Evaluation (AGE) in response to this need. There is concern about the possible impacts of an ad-hoc proliferation of GIS within the Army, particularly now that the technology is widely available on the commercial market. The concerns include whether the stated capabilities of systems can actually meet specific Army functional requirements, how data quality standards can be ensured, and how Army consumers can ascertain that they are selecting a cost-effective solution.

2. AGE PURPOSE

AGE is intended to permit applications and systems scientists to perform in-depth studies of off-the-shelf GIS products (both commercial and public), to provide a structured forum for vendors and developers to showcase their products to potential Army consumers, and to provide an information clearinghouse for all Army components interested in obtaining near-term GIS capabilities. Additionally, AGE will provide the DTSS program with GIS technology updates and will report and recommend innovative and successful GIS implementations which may be incorporated into the system.

AGE is utilizing the analyzed data gathered at the TAWS demonstrations to implement and test some of the recommended functional capabilities derived from these results. The AGE study is also intended to promote competition in GIS acquisition activities by emplacing a work unit that will examine numerous systems to assess developments and breakthroughs in the rapidly advancing GIS field.

There are a number of philosophical premises that led to the AGE project. The first premise is that the field of GIS is changing too fast for the USAETL GIS research program to 'lock' into one particular system or technology. The 'luxury' of 'playing the field' is one not afforded to most operational or developmental environments, but it is a well-suited and essential function for an activity dedicated to GIS research. There is a tendency amongst Federal GIS users today to become dedicated proponents of one of a few particular systems. Unfortunately, only these few of the many systems and software products available have been exercised in depth, not affording an adequate opportunity for some vendors or developers to showcase their systems. This can result in creating a market environment which stifles rather than fosters innovation.

Given the rapid progress in advancing the state-of-the-art in GIS, another AGE project adage is to look for systems which economically can be warranted for a five year or less system lifecycle. This should facilitate the process of upgrading and/or replacing system components and consequently should mitigate the problem of supporting systems that are technologically obsolete and costly to maintain.

From successful results of the Terrain Analyst Work Station (TAWS) program, USAETL researchers concluded that advanced microcomputer technology adequately met Army GIS requirements. Therefore, AGE will focus exclusively on GIS products which operate on supermicrocomputers (engineering work stations) or microcomputers (advanced personal computers). Since the Army GIS requirements can be satisfactorily addressed using microcomputer technology, there is no need to examine products which operate only on larger, more expensive systems. Also, by utilizing as small a system as technologically feasible, the AGE goal of maintaining a short product lifecycle can be economically realized. Preliminary study indicates that personal, desk top microcomputers may have limited utility in addressing the extent of processing requirements and the density of data needed for most military applications; therefore the bulk of the evaluation will be committed to examining engineering work station

GIS solutions. However, advances in desk top or lap top (highly portable and compact) microcomputers are of great interest to the researchers. When these sized and priced systems can host GIS that satisfactorily address Army geographic data processing requirements, all echelons will be able to derive the benefits of computer assisted terrain analysis.

It is probable that several systems may partially meet the Army GIS requirements, but there may not be any one system which optimally addresses all the requirements. If this turns out to be the case, the AGE program will evaluate whether there should be an amalgam of several system components combined into a single, multipurpose work station or the use of several, dedicated GIS work stations to address the total GIS functional requirements.

The AGE concept was introduced in late fiscal year 1987. The Army GIS Evaluation is a multi-year effort, but the actual system tests will be confined to a two year period that will be initiated in the second half of fiscal year 1988. This way, systems selected for study at the onset of the project can be evaluated in roughly the same technological context as those selected later in the project. The project may be renewed in two years, but it is expected that the field will have evolved to the level that those systems selected for the second study cannot be evaluated using the same framework as the initial study. The short evaluation period also ensures that results are disseminated to Army customers as rapidly as possible.

3. S-GIR PURPOSE

The TAWS demonstration results indicate that the most critical Army GIS design area is the soldier-to-GIS interface. Therefore, the USAETL GIS research program will focus its development activities on the design of a specialized user interface. This work unit, called Soldier-to-GIS Interface Research (S-GIR), will create and study several user interface designs on a dedicated rapid prototyping system. The results of the experimental designs will be used to develop an advanced user interface to serve as a front-end for GIS applications modules.

S-GIR will utilize commercially available, low cost rapid prototyping software to explore different approaches to developing the user interface design. The designs will be keyed to preliminary performance standards derived from Army GIS functional requirements. The designs will implement, as much as possible, direct manipulation interface technologies. That is, they will employ a highly interactive, graphical interface that presents to the user all alternative courses of action and permits the user to execute (or, if needed, reverse), in a single step, the intended operation. S-GIR will utilize multiple process windows, pop-up and pull-down menus, graphic icons to depict commands or functions, and comprehensive 'help' functions.

The S-GIR study goal is to strive for simplicity of operations without limiting the GIS functional capabilities. The underlying philosophical premise to S-GIR is that the applications modules should conform to the way that the user perceives and expects to interact with the system (and not vice versa).

S-GIR is a multi-year program. During the first phase, the experimental designs will be developed on the dedicated prototyping system. The prototyping system will not contain working GIS modules; it will just serve as a dynamic design mock-up. Each mock-up iteration will be evaluated by researchers and soldier users. The resulting analysis will be used to prepare a specification for a soldier-to-GIS subsystem. The second phase of S-GIR is to develop a methodology in which to implement the specified design as a front end for operational GIS applications modules. At this phase in the study, the AGE results will be utilized to select the best suited system(s) to work in conjunction with the new interface subsystem. Most probably, the design will be implemented using a standard windowing protocol which can be implemented on an engineering work station. After the interface has been implemented with working GIS software, a suite of computer-aided instruction (CAI) modules will be developed to work with the system. Long range S-GIR goals include the development of an 'intelligent interface' with an expert system terrain analyst's toolbox to assist and support the process of terrain analysis. The terrain analyst's toolbox will employ adaptive interface techniques to provide appropriate levels of guidance and cues to the users which will be based on the types of inputs received.

4. REQUIREMENTS ASSESSMENT

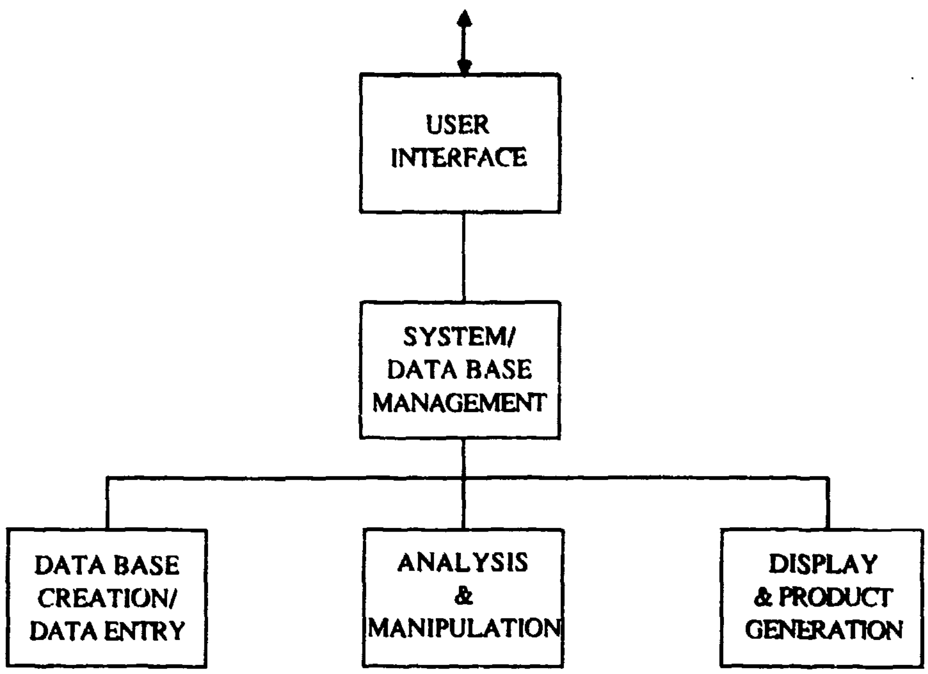
The first phases of the S-GIR and AGE projects involved developing baseline functional requirements. The requirements are analyzed and used to derive system performance standards. The requirements and their corresponding performance standards serve as a paradigm for which benchmark tests can be formulated.

A simple model was devised to develop a conceptual framework and provide a structure for studying GIS functions. The model, depicted in Figure 1, divides geographic information systems into five functional subsystems: the user interface, system / data base management, data base creation / data entry, analysis and manipulation, and display and product generation.

The user interface is the subsystem through which all human interaction with the applications modules are made. Although the S-

GIR project entails developing a specialized user interface, this subsystem of each off-the-shelf GIS will still be assessed in the AGE project. The user interface subsystems will be evaluated with respect to both the effectiveness of the interface as it functions with the other components of the GIS, and the potential for modifying or building a shell around it (such as the one to be developed through the S-GIR project).

Figure 1. GIS Functional Model



There are some targeted performance standards for the user interface subsystem. The user interface should facilitate the process of learning to operate the GIS, and it should provide the user with an efficient and effective means to invoke the full intended functionality of the system. By the end of the first day of use, the Army terrain analysts should be able to, at a minimum, accomplish a tangible task or set of functions using the GIS. The soldiers should be able to learn to use the full functionality of the GIS in about two weeks. Mastery of GIS skills is recommended to be obtained in about two months or less. The system should motivate and expedite terrain analysis processing by both soldiers who have acquired the expertise on the system and novice users. It should not encumber the performance of skilled users nor hinder the learning process of new users. The user interface should permit the user to have flexibility in accessing and manipulating the data base, but it must also utilize protective measures to ensure the integrity of the data.

Certain techniques may be employed to enable a system to meet these performance standards. These include (but are not limited to) providing effective documentation and meaningful on-line error messages, providing data base 'locks' and 'keys' to protect the integrity of the data base, supporting reversibility of operations, and offering the user an array of choices to select from (rather than relying on the user to first formulate the possible alternatives, select the best suited one, and then recall the proper procedure for invoking that function). The user interface should be designed so that each system function has a direct relationship with each logical step in the terrain analysis process.

The system / data base management component of a GIS establishes what types of data can be stored in the system, how they are stored, and how all the applications modules access the data. The major functional component of this subsystem is the querying or retrieval capability. The GIS should be able to manage both vector and raster formatted data. The data bases may be either aggregated or divided into thematic overlays. (Tactical terrain data may be distributed in an aggregated form and most probably will be the major source of digital terrain data bases for the Army.) The Army GIS will typically manage three types of overlays: factor overlays, functional overlays and composite overlays. Factor overlays are the standard thematic overlays found in the current hardcopy DMA terrain analysis products called the Tactical (1:50,000 scale) and Planning (1:250,000 scale) Terrain Analysis Data Bases (TTADB and PTADB). They are: soils and surface materials, slope, drainage, transportation and lines of communication, vegetation, and obstacles. Functional overlays are special purpose or application specific thematic layers. Some examples of functional overlays are an overlay depicting troop or supply locations that might be needed for a logistics application, cloud cover or precipitation data that might be needed for a meteorological model, or detailed water resources and geological overlays that might be needed for an engineering application. Composite overlays are the byproduct of a query or analytical operation. A composite overlay is a derived data layer from one or more factor or functional overlays. An example is a composite overlay derived from a query to the vegetation and soils and slope factors which have met a particular set of criteria and which may be used as one component of a cross country mobility model.

Some of the specific requirements for the system / data base management capabilities for the Army GIS are outlined in the following chart.

SYSTEM / DATA BASE MANAGEMENT CAPABILITIES

Data Base Structure

* World wide capability
* Map sheet independent
* Variable sized manuscripts accommodated
* Thematic overlay handling
* Aggregated data sets handling
* Meta-data handling
* Topological and non-topological capability
* Multiple data structures (raster types, vector types)
* X-Y and X-Y-Z data handling
* Functional, factor and composite overlays
* Multiple attributes and microdescriptors
* Attribute tags at all spatial entity levels
* Edge matching

Querying Capability

* Any / all attribute combinations
* Feedback on estimated time to complete
* Arithmetic operands
* Data type specific or global
* Within or across thematic layers
* Conditional (if / then) queries
* Queries saved as procedural macros
* Queries global or on active window or user-specified area

Data Management

* Standard and special purpose attribute assignments
* Look up tables for all data base codes
* Data dictionary capability for all layers, products
* Lock keys for data base protection
* Save or delete overlays in part or as a whole
* Data base status reports: quality, contents
* Sort, redefine data base
* Data base indexing
* Standard (default) and nonstandard file naming convention
* Browse or previewing capability
* Attribute editing interactively or batch update
* Modification, deletion or addition of graphic elements
* Quality assurance checks

System management

* Transaction log
* Maintainability, supportability
* Links to other systems (data capture, modeling, etc.)
* Ability to enhance / modify
* Password protection
* Operating system independence

The data base creation / data entry subsystem supports the method in which the terrain data are brought into the system. It is limited by the types of data which can be stored and controlled via the data base management subsystem, or by data which can be converted to a usable form via the analysis and manipulation subsystem. Editing of digital data is a function of this subsystem, as is topological structuring and verification. Both the graphic and attribute components of the data must be able to be edited both at the time and after they are digitized. Certain threshold values for connecting line segments, weeding or thinning extraneous points should be available as default operations but should also be modifiable by the operator. Other data quality checks are also components of this portion of the GIS. Generally, terrain data can be brought into a GIS via digitizing (hardcopy) cartographic or photographic products or via reading in and utilizing digital (softcopy) image or geographic data. Some GIS support data base creation as an integral component of the system while others provide the ability to import data from external data capture systems. Although the terms are sometimes used synonymously, data entry refers to the importing of digital data that has been created externally, while data base creation refers to the process of generating a digital data base locally.

The Army GIS must be able to utilize standard (and proposed standard) Defense Mapping Agency (DMA) digital products, such as Digital Terrain Elevation Data (DTED) and Tactical Terrain Data (TTD). Additionally, the systems must be able to import data bases or digital products (symbolized composite overlays) created on other terrain analysis systems, such as the Digital Topographic Support System (DTSS) or from dedicated data capture or image exploitation systems.

The only economically feasible manner in which to utilize data created externally on different systems is to employ standard exchange formats. The GIS researchers are, therefore, closely following the efforts within the Defense and Federal mapping communities to establish standards and specifications for the interchange of digital geographic data. The systems selected for evaluation will be assessed with regard to their ability to be modified, if needed, to input and utilize standard formatted data. When data exchange standards are implemented, a mandatory requirement for an Army GIS will be to throughput in these specified formats.

The scarcity of available digital terrain analysis data bases is the most serious obstacle impeding the widespread use of GIS in tactical and planning military applications. Therefore, the data entry / data base creation subsystem plays a particularly crucial role in a GIS. Advances in data capture technologies, such as scanning digitizers with character reading capabilities and advanced image analysis and automatic feature recognition systems will greatly increase the utility of GIS. If a GIS supports a local data base creation capability, it should be able to support digitizing of hardcopy terrain products or images in as rapid and efficient a manner as possible. Attribute tagging of the graphical features, and clean up and editing of digitized graphics are typically so time consuming that, in many cases, the time dedicated to building an initial data base overshadows the time savings realized in performing the data analysis and product generation on a GIS. A revolutionary breakthrough in the use of GIS will occur if quantum leaps are made in data capture technologies. Otherwise, GIS usage will increase in a more gradual manner as the holdings of digital data archives increase through steady, time intensive efforts to construct the data bases.

The analysis and manipulation subsystem forms the nucleus of the GIS. This capability, working in concert with the data base management subsystem, distinguishes a GIS from other computer-based mapping systems. The analysis and manipulation subsystem supports data base transformations, classifications, statistical analysis, proximity analysis and mensuration functions, and arithmetic, algebraic and geometric manipulations.

Data base transformations are a broad class of operations which include: map projection or coordinate transformations, data structure reformatting, logical or physical file structure reformatting, attribute conversions, geometric corrections or registration adjustments either between data base layers within an area or between adjacent areas, unit of measurement conversions between metric, imperial or U.S. conventions, and valid scaling operations.

Location identification is a major GIS mensuration operation required for Army use. This includes: location identification by place name or description, by coordinate input or Milgrid identification, or graphically via a pointing device. Other mensuration functions include computing distance (path or straight line), length, centroid, area, volume, perimeter of features or of specified parameters. Required proximity functions include buffer operations and spatial neighborhood analysis, which is the ability to query and conduct GIS operations based on adjacency or 'nearness' as a criteria.

The statistical analyses should accommodate cases of both certainty and uncertainty. The statistical functions were not extensively utilized on TAWS; however, as GIS are utilized more extensively and in a more sophisticated manner, these capabilities will most probably be required to support modeling of various phenomena. Classification functions include grouping, sorting, deleting and merging data entities based on both quantitative and qualitative criteria. The mathematic functions include arithmetic manipulation on numeric attributes of the data, geometric adjustments such as rotating, stretching and warping, interpolation, contouring and generalization, and the algebraic operations working in conjunction with the data base management querying capability.

The analysis and manipulation subsystem should support the generation and execution of specific models or simulations. These include mobility, physical distribution, environmental effects, intervisibility, terrain analysis and engineering models. Some special purpose functions such as elevation modeling, adjustments to horizontal or vertical exaggeration, profiling, shaded relief and aspect mapping, and the ability to merge thematic overlays with elevation or image data are useful in some military applications.

The display and product generation subsystem supports the creation of graphical or text output which are either routed to display devices to depict activities occurring in the GIS, or as products which are routed to either display devices for analysis, to digital storage media for use on other computer based systems or to hardcopy output devices. The two major components of this subsystem are the cartographic assignment and report writing capabilities, and the display and output device control functions.

The GIS should be able to generate hardcopy products in both standard military map formats and in project specific formats. This includes use of symbols, colors, labels; legend and title placement; and the ability to place add-ons and insets on the map product. The softcopy products may be used by other GIS based systems, by command and control systems, or as electronic map background display. They must be output in standard digital product formats as needed.

The display and output device control functions determine how products are developed and on what types of hardware on which they can be displayed or output. The Army system should be able to create a display window or zoom into an active map display based on utilizing a pointing device, identifying corner coordinates or center coordinates with a specified radius, or via a spatial entity (state, region, or other designated place name). The process of routing graphic data from the display screen to an output device should be simplified through an efficient link between the user interface and the display subsystem. The entire process of cartographic assignment can be very lengthy, particularly if the system is sensitive to differences in display and plotting devices and consequently requires the user to repeat several processes to transfer products from one device to another. For example, if a system requires that the operator re-assign or modify a product on a display screen prior to plotting on a hardcopy output device, this is time consuming and frustrating to the operator. The ideal procedure for a GIS would be to automatically adjust and modify the product as needed when a change in output device is made. Much of the initial cartographic assignment should be done automatically if the user is generating a standard product. But to ensure an effective and aesthetic presentation, the user should be able to interactively adjust the plot or report as needed, preferably via a direct manipulation interface.

5. PROGRAM STATUS

A small GIS laboratory has been established at USAETL to conduct the AGE and S-GIR projects. The phase one S-GIR system will be designed in-house with prototyping support from Colorado State University.

AGE will be an in-house effort accomplished with the cooperation of the GIS vendors selected for the study. GIS vendors have been solicited for AGE via the 'R&D Sources Sought' column of The Commerce Business Daily, and through professional meetings such as this one. Interested vendors and developers will be asked to fill out a questionnaire regarding the general capabilities of their systems, the notable features of the GIS, the required hardware configuration(s), the costs proposed for the study, the costs of the system should it be procured, the accessibility of the software source code or import and export routines, the support provided for the study and the support required by the government. The research team will select several systems in the desk top / personal microcomputer class and several systems in the advanced engineering work station class based on the questionnaire results. Vendors that are selected for the study will be expected to loan their systems to the government at no charge but will be reimbursed for non-recoverable expenses such as documentation and training costs, the cost of equipment transport and insurance. Systems will be loaned to USAETL for approximately six months.

Researchers are currently preparing six types of test data sets for the AGE. The first data set will be an aggregated data set to simulate the handling of the Tactical Terrain Data because it may be distributed in an aggregated form. The second test case will be an actual hard copy data base which will be typical of the standard terrain factor overlays. Some functional overlays may be added to test certain data base management and analytical capabilities. The third type of data set will actually be several small samples of data from an area in various map projections. The fourth type of data set will include data from various regions of the world. The fifth type data set will include various scale data in variable sized manuscripts and a built up or urban area inset. The sixth type of data set will include various geometric test cases to investigate the limits and accuracies of the systems.

The preliminary work leading to AGE and S-GIR was the development of baseline Army GIS functional requirements derived from the TAWS demonstration results and from discussions with USAETL researchers involved in specifying digital terrain data (DTD) content and format for the Army. The functional requirements are a dynamic document and will be revised as more GIS demonstrations and evaluations are performed. Scenarios for exercising the capabilities of the systems are currently being formulated. USAETL research personnel will utilize the test data sets in the operational scenarios to conduct quantitative and qualitative benchmarking of the performance of the AGE systems. The actual tests are scheduled to commence in the spring of 1988.