TERRAIN ANALYSIS and GEOGRAPHIC INFORMATION SYSTEMS

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A Research Paper submitted to the
Department of Geography in partial
fulfillment of the requirements for the
degree of Master of Science

June 1989

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DEDICATION PAGE:

Most importantly to my Mom and Dad for being the wind beneath my wings.

This paper was also completed with a little help and encouragement from my friends.

Thanks to all

INTRODUCTION

Terrain is an important factor in the integration of fire and maneuver. Sun Tzu, a Chinese philosopher, recognized the importance of geographical knowledge with its application toward successful military operations in his writing *The Art of War*. In 514B.C. he wrote, for a commander to ignore the topography of the battlefield was unacceptable for the execution of any military operation. A commander was then only assured a fifty percent probability of victory.

> "And therefore I say: Know the enemy, know yourself; your victory will never be endangered. Know the ground, know the weather; your victory will then be total." (Sun Tzu 1982 p.124).

The variety of maps required for doing battle has changed through time with the technology of war. The evolution can be traced through balloon observation, air-photography and radar to satellite sensors that have paralleled the succession from black powder and smooth bores, through cordite and rifling via bombers to guided rockets (O'Sullivan 1983).

In the nineteenth century generals could usually see the entire battlefield that they fought over from a vantage point. Detailed topographic maps were not required for tactics at this time (O'Sullivan 1983). Commanders could tell their subordinates where to maneuver by pointing to terrain features that they both could see. The twentieth century saw an increase in lethality and range of guns that demanded accurate topographic maps. The dispersal of units to avoid presenting concentrated targets meant that after World War I commanders above company level could no longer physically see their battlefield and had to fight by map coordinates (Poole 1944).

The increased reach and destructiveness of weapons through this century has induced not only an increase in troop dispersion but also a decrease in the appropriate map scale. In World War I company and battalion commanders used 1:25,000 scale maps (Jackman 1962). In World War II and Korea the standard unit scale was 1:50,000 (Jackman 1962). In Vietnam, airmobile company commanders were forced to use 1:250,000 scale maps because their helicopters flew across the expanse covered by a 1:50,000 sheet before they could figure where they were (O'Sullivan 1983).

Tactical decisions at divisional or lower levels require more detailed and timely terrain information. It is necessary to determine fields of fire for direct fire (line-of-sight) weapons, cover and concealment from enemy fire and observation, the ease of off road movement for tactical vehicles and landmarks for helicopter routes and landing zones (FM100-5 1984). An artillery strike may convert a village crossroads into a tank trap of rubble, or a readily penetrable forest into an instant abatis. The passage of a tank company through an agricultural field may so churn the ground that it is impossible for other tanks to follow.

The increasing importance of terrain characteristics and topographic maps to military operations has made the impact of erroneous or out-of-date maps potentially disastrous. Cultural features such as roads and the extent of the built-up area, may change dramatically between map survey and map printing. On a battlefield bridges disappear, dams are breached and buildings reduced to rubble at a speed faster than the changes can be posted on existing maps (O"Sullivan 1983). In Vietnam, the U.S. Forces used recent aerial photos in place of maps for terrain analysis because of the rapidly changing face of the landscapes in battle zones.

While recognizing that the "weather and terrain have more impact on battle than any other physical factor, including weapons, equipment, or supplies" (FM 100-5 1982), the U.S. Army has recognized that a manual storage/retrieval system is not sufficient. Today's modern battlefield will present more demands for meaningful terrain information that can be collected, processed, and disseminated in a timely manner by a non-automated system.

The purpose of this paper is to define terrain analysis, as it relates to military applications; to review the historical development of the central ideas of terrain analysis, which has led to the development of three computer programs that are designed to make terrain analysis an automated process rather than a manual process.

TERRAIN ANALYSIS: 1950 to PRESENT

After both world wars, a synthesis of physiograhic analysis began to emerge under the title terrain analysis. The four sub-fields of military geography; systematic, descriptive, topical, and regional, each contributed to give the new subfield, terrain analysis, its foundation. Terrain analysis employed the systematic sciences in order to collect and interpret physiograhic information; descriptive military geography showed the critical nature of terrain and validated the need for better prediction of terrain influences; topical military geography gave specific applications for terrain analysis in the fields of military doctrine, clothing, and equipment; and finally,regional military geography formed the structure around which terrain can be appreciated in its total geographic setting.

Although terrain analysis was used extensively during the Second World War, most of the Army's experts left government service at the end of the war. Post war geographic studies, for the most part, concentrated on developing tactics, clothing, and equipment for the world's physiographic regions. This included tactical operation manuals such as: airborne operations, guerrilla operations, infiltration operations, barrier and denial operations, armor operations, airmobile operations, snow and cold weather operations desert operations, jungle operations, mountain operations, amphibious operations, and military operations in urban terrain (this is not an exhaustive list by any means).

After the war, the responsibility for gathering geographic information and intelligence was vested with the CIA, the Defense Intelligence Agency (DIA), and the Army's intelligence and topographic communities. The role of the CIA and DIA, arising out of the wartime agency Office of Strategic Services (OSS), was largely in the realm of strategic, regional, and political geography, while the Army concentrated most of its efforts into cartographic production through the Army Map Service (AMS) with some geographic analysis done by the Topographic and Military Intelligence Branches (Stone 1972).

An overview of the development of terrain analysis is provided in Figure 1.

Terrain Analysis

	Doctrine	Organization	Hardware
1950's	Terrain Studies with Regional Area Emphasis	Department of Defense and Army Level Staff	Photo - Interpretation Kit
1960's	Systematic Military Geography	Research Organizations and Army Topographers in high level Engineer and Intelligence Staffs	Quantitative Studies Tactical Image Interpretation Facility
1970's	Terrain Analysis as Combat Multiplier Intelligence Preparation of the Battlefield (IPB)	Defense Mapping Agency Topographic Battalions (Theater Army Level)	Topographic Support System (Development) Zoom Transfer Scopes
1980's	AirLand Battle	Terrain Teams at Corps and Division Level	Topographic Support System (Fielded) APPS MicroFix TerraBase CAMMS DTSS

Figure 1: Overview of the Development of Terrain Analysis

During the 1950's, terrain analysis was simply another component of the Army intelligence community. Most studies were a carryover from the regional emphasis of WWII. They were largely strategic in scope and were conducted by higher level staffs within the Department of Defense. A good example of this type of strategic terrain study occurred during the Korean conflict of the early 1950's. Tomlinson (1967) discusses the strong dependence on precise terrain information that resulted in General MacArthur's successful invasion at Inchon. In order to gain approval of his risky invasion plan he had to overcome the geographical criticisms from experts working for the Joint Chief of Staff. MacArthur's plan was to arrive in the shallow waters of Inchon Harbor at a time which coincided precisely with one of the exceptionally high tides. Such a landing would have been impossible on all but four dates during the year in which the tide was high enough. Strategic surprise was achieved because the North Korean People's Army did not consider such an invasion route to be feasible. However, this type of analysis was done at the Army staff level.

Following the Korean War and into the 1960's, a great deal of theoretical research in terrain analysis and methodology was done by Waterways Experiment Station (WES), Vicksburg, Mississippi and by the Engineer Topographic Laboratories (ETL), Ft. Belvoir, Virginia. Specific terrain studies were done by the Army Map Service and Army Topographic staff elements, but such studies were limited in scope and general usage. Although computers were used extensively in research, the state-of the-art hardware which was in the field at the time consisted of a collection of aerial photo interpretation tools collectively known as the Tactical Imagery Interpretation Kits (TIIK) and the Tactical Imagery Interpretation Facility (TIIF). Furthermore, the Vietnam War did not provide a definitive need for detailed terrain analysis: understanding and using guerrilla tactics was perhaps more important than analyzing the terrain; the tropical lowlands, rice paddies, and mountain highlands were relatively consistent in terrain features; and the emphasis on air warfare and the absence of tank warfare precluded a large demand for terrain analysis.

However, it was not just the defense of Europe that provided the impetus for increased emphasis and training in terrain analysis. The Arab-Israeli conflicts of 1967 and 1973, with their high speed armor tactics and closely coordinated air interdiction of airfields, were perhaps the most important factors in impressing the military community with the necessity of a quick response geographic and intelligence capability. Shoemaker (1968) describes the quick success of the Israeli Air Force in the 1967 war as resulting in large measure from the accurate intelligence information regarding the location of the most vulnerable of United Arab Republic's airfields and aircraft.

The U.S. Army began the first steps to formalize its terrain analysis program at a lower organizational level in the early 70's, partly because it was recognized that NATO would never achieve tank for tank parity with Warsaw Pact forces. Terrain intelligence was viewed as a force equalizer or combat multiplier. Given good quality terrain intelligence which was both flexible, continually updated, and rapidly retrievable, an outnumbered force could expect to defend itself successfully. This was and still is the basic justification for a tactical terrain analysis system. Definitive doctrinal and procedural guides were published: FM 30-10 *Military Geographic Intelligence (Terrain)* (1972), FM 21-33 *Terrain Analysis*(1978), and the ETL series of *Terrain Analysis Procedural Guides* (begun in 1979). During this time period the concept known as the Intelligence Preparation of the Battlefield (IPB), was introduced. IPB combined with terrain information and other intelligence about the enemy provides with reasonable accuracy an estimate of what routes and courses of action the enemy may take.

The Defense Mapping Agency (DMA), established in 1972, became active during the 1970's in developing a terrain analysis data base which could be synthesized and manipulated by trained soldiers in order to produce meaningful and useful terrain products for commanders. The result was the production of DMA's Tactical Terrain Analysis Data Base (TTADB) at a scale of 1:50,000. Additionally, a planning data base was designed at 1:250,000.

These data bases consist of seven thematic overlays: 1) surface configuration (slope), 2) vegetation, 3) surface materials (soils), 4) surface drainage, 5) lines of communication (transportation), 6) obstacles, and 7) water resources (FM 5-105 1985). The system was designed so that, given these seven elements, an Army terrain analyst could produce a wide variety of terrain intelligence products which would meet the commanders needs on the battlefield, as depicted in Figure 2. Producing these overlays is a tedious manual process of viewing aerial photographs in stereo, studying landform patterns, making measurements, conducting field checks for ground truthing , if possible, and researching published materials (Figure 3). By combining

Synthesis Process

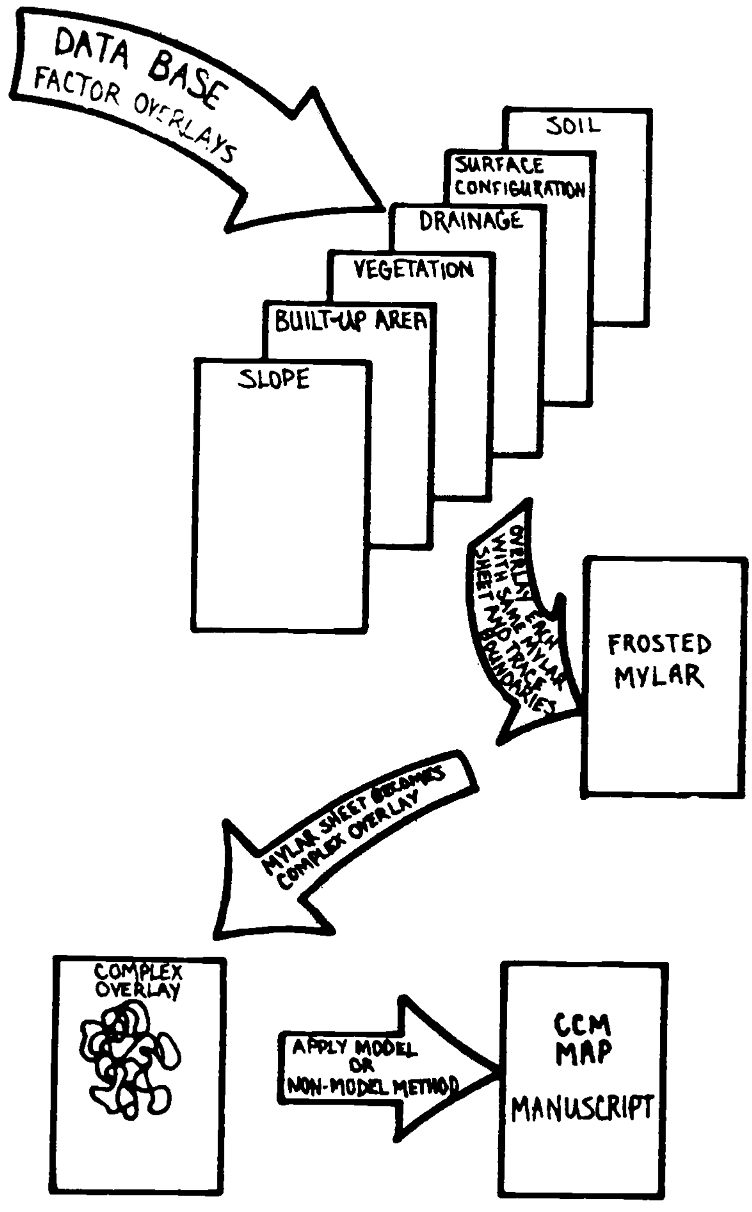


Figure 2 (Messmore et al. 1979)

Military Aspects of Terrain (OCOKA)	Elements of Terrain Information	Example of Terrain Analysis Products
Observation/ Fields of Fire	Vegetation (summer & winter) Surface configuration Battlefield environmental effects on the terrain Urban areas	o Horizontal line-of-sight for direct-fire weapons and radar. o Emplacement suitability and performance ratings for ground surveillance
Cover and Concealment	Vegetation (summer & winter) Surface configuration Obstacles (micro relief) Battlefield environmental effects on terrain Urban areas	o Cover potential from direct and indirect fire (good/fair/poor). o Concealment potential from horizontal and vertical observations (good/fair/poor).
Obstacles	Vegetation (summer & winter) Surface configuration Drainage characteristics Natural and man-made Micro relief Surface materials (wet & dry) Urban areas	o Location of existing natural and man-made obstacles. o Mobility potential on the battlefield expressed in GO, SLOW-GO and NO GO for track and wheeled vehicles.
Key Terrain	Urban areas Lines of communication Surface configuration Drainage characteristics	o Location of natural and man-made features as key terrain such as landslide areas, bridges, check-points, high ground, and key military installations.
Avenues of Approach	Vegetation (summer & winter) Urban areas Surface configuration Surface materials (wet & dry) Drainage characteristics Lines of communication	o Identification of areas where movement of friendly and enemy forces may occur. o Speed prediction.

Figure 3 (FM 5-105 1985)

information from one or more of these overlays with weather data and the operational parameters of tactical equipment, the terrain analyst provides the commander with an analysis of the effects of terrain and weather on contemplated operations.

During the 1970's these terrain data bases were introduced into the Army's topographic battalion's at the Theater Army level. Later in the decade, terrain teams were formed in support of each Combat Corps and Division. At this same time, equipment to assist analysis and synthesis of terrain in formation and to support the hard copy output of these terrain teams was assembled and placed in specially designed air-conditioned trailer modules. When this author attended the Mapping, Charting, and Geodetic Officer's Course in 1981, the prototypes of the Topographic Support System (TSS) were shown as the state-of-the-art terrain analysis hardware. However, TSS was delayed in its fielding to topographic battalions (due largely to budget cuts) until 1985, when the majority of the equipment within these modules was considered obsolete.

Terrain and weather, while presenting equal faces to both sides in a conflict, gives the advantage to the side which is able to gather and utilize the most military geographical information. The advantage goes to the side which can anticipate the effects of weather, reinforce natural terrain obstacles to its benefit, and anticipate the enemy's action based on geographic constraints. The next battles will move fast. With each new situation, timely terrain intelligence products which are able to meet the tactical commander's demands will make the difference in who wins the battles and ultimately the war. Additionally, a key element of any terrain analysis system in the future will be the capability to quickly analyze lines of sight over large distances and display areas which are masked from line of sight intervisibility from a given observation point.

The terrain analysis system in use in the Army today is half a manual system and half an automated system. The drawbacks for not being completely automated are 1) data bases (previously mentioned) are neither complete nor fielded to the appropriate topographic unit, 2) lack of trained personnel and 3) maintenance and logistic problems. As such, the process is slow when compared to a complete computer based geographic information system in use throughout state and federal agencies today. Factors such as data base construction and analysis costs, hardware costs, budget priorities, or the need for human involvement in the synthesis process may also be pertinent. In order to better understand the computer programs/systems that have been developed and fielded and that are still being tailored, the manual terrain analysis system will be examined. This will be followed by a discussion of the capabilities of TerraBase, a microcomputer-based military terrain information system which many terrain teams are now using. Next Microfix v2.2, the first microcomputer-based terrain system fielded in the Army; followed by a description of the Condensed Army Mobility Model System (CAMMS).

A specific request from a military commander begins the synthesis of a terrain product for either the manual terrain analysis system or for any of the automated terrain analysis systems. However, in the manual system, the terrain analyst pulls the appropriate thematic overlays and other data from his storage files, synthesizes the required information by placing the overlays on top of each other and manipulating the associated data (as well as synthesizing the data), and then manually traces out the finished product. Aerial photographs may be consulted if available. This system has great flexibility in that a product can be specially tailored to meet exact the needs and specifications of the user. An overhead concealment product could be produced for any season of the year using knowledge of the deciduous nature of trees. A cross-country movement (CCM) graphic could be made for wet or dry conditions; for wheeled or tracked vehicles and so on. But the severe drawback of this method is the time consuming manual construction. A CCM product could take considerably longer, up to 30 hours, depending on the complexity of the area and the expertise of the terrain analyst (the time estimate is based on first hand knowledge from being a member of a theater terrain team and as a commander of a cartographic company). The 30 hours do not take into consideration press time for multiple copies.

The terrain analysis system does work, despite the slow response time and the cumbersome data base overlays that must be stored. However, something is better than nothing. For example, in the Granada operation, a 24 hour notice was served to the topographic battalion that this author was in, for multiple copies of the famed tourist map. The result was a monochrome copy with a military grid overlay, so that targets could be located for artillery fire missions. In defensive situations such as the U.S. role in Korea and the NATO defense of Europe, the need for rapid response time is mollified by the need for advance defense planning and war gaming over known terrain. Terrain studies and CCM products can be produced for likely battlefields well in advance.

The aforementioned advantages of the present Army terrain analysis system have arisen in part from the organizational structure the Army has chosen to utilize. In contrast to the geographers of World War II who conducted studies in Washington D.C., to aid in the strategic planning at the Pentagon, today's terrain analyst belongs to a Terrain Team at the Theater Army, Corps, and Division level. At this level, terrain information is both more accessible and more responsive to the tactical needs of commanders of Division, Brigades, Battalions, and Companies. Much of the quality and flexibility of the terrain products depends on the subjective understanding and decisions of the personnel on the terrain team.

In short, the primary advantages of the present Army terrain analysis system are its flexibility, responsiveness to user's needs, and its ability to produce accurate meaningful terrain intelligence. The primary disadvantages are its slow response time (relative to wartime response needs), and to a lesser degree, the cumbersome nature of its database overlays.

GEOGRAPHIC INFORMATION SYSTEMS AND MILITARY INFORMATION SYSTEMS

A geographic information system (GIS) is a powerful tool for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes (Burrough 1988). A GIS describes objects from the real world in terms of 1) position with respect to a known coordinate system, 2) attributes that are unrelated to position, and spatial interrelations with each other; which describes how they are linked together or how one can travel between them.

This history of using computers for mapping and spatial analysis shows that there have been parallel developments in automated data capture, data analysis, and presentation in several broadly related fields (Burrough 1988). These fields include topographical mapping and cartography, surveying and photogrammetry, rural and urban planning, soil science, geography, and remote sensing and image analysis. Military applications have overlapped and even dominated several of these fields. Consequently, there has been much duplication of effort and a multiplication of field specific jargon for different applications for different purposes. This multiplicity of effort in several initially separate but closely related fields is now resulting in the possibility of linking many kinds of spatial data processing together into truly general purpose geographical information systems, as technical and conceptual problems are overcome (Burrough 1988).

However, a GIS should be thought of as being much more than a means of coding, storing, and retrieving data about characteristics of the earth's surface. In a real sense the data in a GIS, whether they have been hard copied on a sheet of paper or as invisible marks on the surface of a magnetic tape, should be thought as representing a dynamic model of the real world (Burrough 1988). These data can be accessed, transformed, and manipulated interactively in a GIS; and can serve as a model for studying environmental processes or for analyzing the results of trends, or anticipating the possible results of planning decisions.

Geographic information systems differ from computer graphics because the latter are largely concerned with the display of an image. However, good computer graphics are essential to a modern geographic information system but a graphics package is not by itself sufficient for performing tasks expected (Burrough 1988).

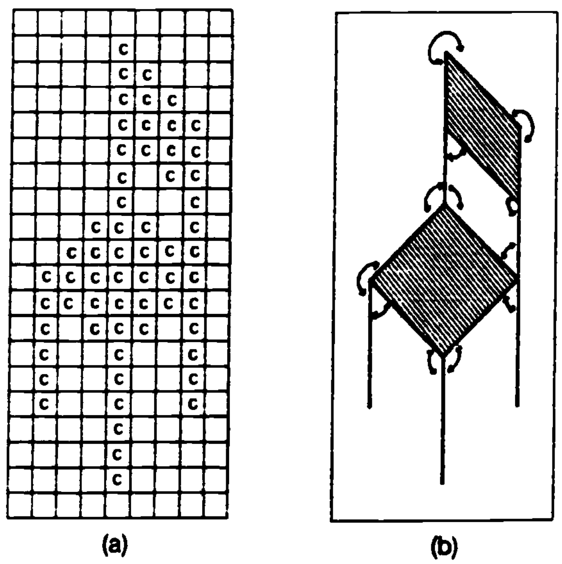
A GIS does not differ from a military information system (MIS), except that the applications of a MIS are military oriented. So, the following discussion on what a GIS should be able to do, as well as, operative and functional criteria can be applied to the three military information systems mentioned earlier; and in fact will be used to review each. Operative criteria refers to the general hardware/ software characteristics of a system. Functional criteria deal with four components: data capture, editing, analysis, and output.

Data input covers all aspects of transforming data captured in the form of existing maps, field observations, and sensors (including aerial photography, satellites, and recording instruments) into a compatible digital form. The creation of a clean, digital database is a most important and complex task upon which the usefulness of the GIS depends. It is the ability to process the cartographic features in terms of their spatial and non-spatial attributes that is the main distinguishing criterion between automated cartography (where the non-spatial data relate mainly to color, line type, and symbolism) and geographic information processing (where the non-spatial data may record land use, soil properties, vegetation types, and slope aspect).

There is no single method of entering the spatial data to a GIS. The choice of method is governed largely by application, budget, and the type of data being input (Burrough 1988). The types of data encountered are existing maps, including field notes and hand drawn documents, aerial photographs, remotely sensed data from satellite or airborne scanners and point sample data (i.e. soil profiles). In addition, the actual method of data input is also dependent on the structure of the database of the GIS, raster or vector.

The raster and vector methods for spatial data structures are distinctly different approaches to modeling geographical information. Raster data structures consist of an array of grid cells. Each grid cell is referenced by a row and column number and it contains a number representing the type or value of the attribute being mapped.

Vector data structures consist of three main geographical entities, points, lines, and areas: points are similar to cells, except that they do not cover areas; lines and areas are sets of interconnected coordinates that can be linked to given attributes (Burrough 1988). Figure 4 gives a graphic comparison of raster and vector structures; and Table 1, from Burrough (1988) lists the



A chair in (a) raster or grid-cell and (b) vector format.

Figure 4 (Burrough 1988)

Comparison of vector and raster methods

Vector methods

Advantages
- Good representation of phenomenological data structure
- Compact data structure
- Topology can be completely described with network linkages
- Accurate graphics
- Retrieval, updating and generalization of graphics and attributes are possible

Disadvantages
- Complex data structures
- Combination of several vector polygon maps or polygon and raster maps through overlay creates difficulties
- Simulation is difficult because each unit has a different topological form
- Display and plotting can be expensive, particularly for high quality, colour and cross-hatching
- The technology is expensive, particularly for the more sophisticated software and hardware
- Spatial analysis and filtering within polygons are impossible

Raster methods

Advantages
- Simple data structures
- The overlay and combination of mapped data with remotely sensed data is easy
- Various kinds of spatial analysis are easy
- Simulation is easy because each spatial unit has the same size and shape
- The technology is cheap and is being energetically developed

Disadvantages
- Volumes of graphic data
- The use of large cells to reduce data volumes means that phenomenologically recognizable structures can be lost and there can be a serious loss of information
- Crude raster maps are considerably less beautiful than maps drawn with fine lines
- Network linkages are difficult to establish
- Projection transformation are time consuming unless special algorithms or hardware are used.

Table 1 (Burrough 1988)

advantages and disadvantages of the two methods.

Data transformation includes editing and updating and the large array of analysis methods that can be applied to the data in order to obtain answers to the questions asked of the GIS.

Computer analysis of data is the primary function of a GIS. When a GIS is designed, the designer should expect that a user/customer will want to ask an unlimited number of questions. So, the GIS should be capable of answering them by using certain combinations of data retrieval and transformation operations. Even though there are questions that will not be anticipated, listed from Burrough (1988), are some general questions that a GIS should be capable of answering:

a) Where is object A?

b) Where is A in relation to place B?

c) How many occurrences of type A are there within distance D of B?

d) What is the value of function Z at position X?

e) How large is B (area, perimeter etc.)?

f) Reclassify objects having certain combinations of attributes.

g) Using the digital database as a model of the real world, simulate the effect of process P over time T for a given scenario S.

Data output and presentation concerns the ways the data are displayed and the results of analysis are reported. A variety of output products can be produced by a GIS: maps, graphs, charts, and reports. Output devices are many: line printers, fixed carriage typewriters, drum and flatbed plotters, electrostatic printers and/or cathode ray tube (CRT) terminals. The variety of output devices is rapidly increasing: i.e., color xerography. Maps are probably the most demanded item from a GIS. While manipulation techniques are sophisticated, mapped output remains fairly rudimentary, although higher standards are being implemented.

SYSTEM REVIEWS

The purpose of this system review is to provide a general impression of systems that have been designed specifically for terrain analysis, their characteristics, and their limitations. This review is by no means an exhaustive inventory, considering these systems are continually being updated/developed as user feedback reaches those the developers; and this report will not attempt to make a judgment on which system is the best. However, the author will offer a suggestion of unity of effort in the conclusion section.

The materials reviewed here were obtained from Major Clark K. Ray Jr. of the United States Military Academy, Major Monte Pearson, of the Waterways Experiment Station, and WO3 Norm Price of the Defense Mapping School.

MICROFIX

The MicroFix (QRC-55) was the first microcomputer information system fielded to Army topographic battalions. The system is simply a hard cased Apple II computer with a 20 mb hard disk drive and a videodisk player. Version 2.2, now called the MicroFix Topographic Workstation, provides the terrain analyst with an automated capability to determine the effects of the terrain and weather on the battlefield.

The V2.2 MicroFix Topographic Workstation contains two parts: a baseline configuration common to all MicroFix systems and the topographic package. The baseline software maintains graphic and text data bases that can be overlaid on maps stored on the system's video disk unit. The topographic package represents a cooperative effort among Army laboratories and units.

The main menu of MicroFix contains the following: Digital Terrain Mapping, Weather/Environment, Mobility Calculator, Unit Conversions, and Coordinate Conversions.

The Digital Terrain Mapping (DTM) software provides digital topographic support. This program uses Digital Terrain Elevation Data (DTED) Level I produced by the Defense Mapping Agency (DMA) which have been reformatted for use with MicroFix. DTM can draw and print the following types of output: contour maps, tinted elevation, slope, and speed maps, visible area plots for intervisibility on the ground or low flying aircraft or at constant elevation, line-of- sight profiles, oblique views and perspective views. Map images may be overlain in any combination and completed maps may be overlain with UTM ticks, numbered ticks, or a grid. Images may be stored on the hard disk, and then recalled to the screen for later use.

The Mobility Calculator is a MicroFix application that allows the user to perform predictions of the speed at which any of a number of standard US and Warsaw Pact vehicles can negotiate different types of terrain.

The user specifies the scenario by making several menu choices . The Mobility Calculator uses two different models to predict speeds, usually producing two answers.
Each model has its strengths and weaknesses, and the analyst must determine which is most appropriate for a given situation.

The Condensed Army Mobility Model (CAMM) developed by the Waterways Experiment Station calculates forces on the vehicle as closely as possible and therefore tends to be very accurate (Forscom Manual 1987). To obtain these more accurate results, however, the model requires detailed information about the terrain.

The Defense Mapping Agency Cross Country Mobility Model (DMACCMM) is designed to be a manual method. It is simpler and requires less information, therefore, the results are less accurate than CAMM. In addition, some vehicles supported by CAMM are not included in DMACCMM. An advantage of the DMACCMM is that it considers obstacles and the current version of the CAMM does not (Forscom Manual 1987).

The unit and coordinate conversion options simply lets the user change the parameters the user is operating in (e.g., feet to meters or UTM coordinates to Latitude/Longitude).

While MicroFix has filled a critical gap in the Army's terrain analysis program, it is not a comprehensive digital terrain analysis system. The digital data stored by MicroFix contain only the feature information regarding specific locations. It does not have the capacity to store large files of digital data as required by a full geographic information system.

TERRABASE

TerraBase, is described as "what a word processor is to text, TerraBase is to terrain" (TerraBase User's Documentation 1988,pg.1), a microcomputer military information system that uses many features of current geographic information systems, tailored for use by terrain analyst in the field. This system is completely user-oriented and requires little or no familiarity with computers.

TerraBase was designed to run on the Zenith 248 microcomputer and Epson-compatible Alps America printer. The minimum configuration is:1) Zenith 248 with 20 mb hard disk drive (or any IBM-AT compatible with 512k memory and EGA), 2) Zenith color monitor (or any EGA-RGB monitor), 3) Alps printer (or any Epson FX compatible) (TerraBase User Documentation 1988).

The SummaSketch graphic input tablet device is used to enter geographical information from TTADBs and maps or photos. TerraBase also supports the Emerald DOS 80-8000, a 9 track tape drive. This tape drive can be used to bring into the system DTED level I and Landsat Thematic Mapper tapes recorded in ASCII standard 1600 bits per inch format as provided by the Defense Mapping Agency (TerraBase User Documentation 1988). Finally, if color output is desired, the software supports the Alps 318 and Epson EX 800 and 1000 printers, which still can do black and white copies, but can also provide maps with up to 16 shades.

The forms of data supported by TerraBase are Digital Terrain Elevation Data (DTED) Level I, Landsat Thematic Mapper (TM) data, Tactical Terrain Analysis Database (TTAD) factor overlays (digitized by the user), and Point/Area/Linear (PAL) Feature Data taken from maps and overlays. Figure 6 shows the products that TerraBase is capable of producing. TerraBase's main menu consists of three selections: 1) Data Importers, 2) Digital Terrain Mapping, and 3) Utilities.

The Data Importers section loads the different types of data used by the system. Most of Terrabase uses raster data, with elements of information arranged in an uniform grid over the terrain. TerraBase PAL Data are not raster, but are vector data.

Digital Terrain Mapping uses the imported data for analysis and production. DTED is used to produce elevation layers, such as contour, slope, and visible area maps. It is also used for non-layer data sets, such as perspective, oblique, line-of-sight, and dynamic parallel views. Landsat layers can depict supervised classifications of Landsat data with tints indicating categories such as vegetation, urban, and water. Tactical Terrain Analysis Data Base (TTADB) layers produced from TTADB factor overlays are tinted according to cross-country mobility or user-specified criteria. Point/Area/Linear (PAL) layers contain special features digitized from maps or photographs and stored in the digital data base. Products may be layered, stored for future recall, or printed in black and white or color.

Utilities support useful functions not directly related to the terrain data. The Graphic Screen Utility allows users to recall and print images stored earlier. The Mobility Calculator determines the speed of cross-country travel for various U.S. and Warsaw Pact vehicles, using CAMM and DMA's cross-country model, based on given terrain conditions at a point. Coordinate Conversions translate UTM coordinates to latitude/longitude and vice versa. Sunrise/Sunset/Moon Phase software provides almanac data, and the historical climatology function interactively retrieves data from a weather database for four areas of the world (West Germany, Korea, Middle East and Central America). The Aircraft Load package calculates how density altitude affects load lift capacity for certain fixed wing and rotary wing aircraft. Units conversion automates the conversion of units of measure. The Printer Pattern Editor allows the user to modify the patterns used to represent screen tints in printed products. The Configuration Editor allows the user to set system wide defaults to tailor TerraBase to the particular computer and peripherals in use.

CONDENSED ARMY MOBILITY MODEL SYSTEMS (CAMMS)

CAMMS provides a comprehensive description of the ability of vehicles and vehicle convoys to transport soldiers and material over virtually any type of terrain, on-road or off-road, under nearly any weather conditions. First generations of the CAMMS were developed in the early 1980's to provide a predicting capability for microcomputer systems such as the Apple II (i.e. MicroFix), which existed at the time. Today, CAMMS equipment requirements are as follows: 1) Zenith 248 or compatible that runs DOS version 3.2 or later, 2) math coprocessor, 3) EGA monitor, 4) at least a 20 mb hard disk drive, 5) Alps

P2000G printer or any wide carriage Epson, and 6) SummaSketch digitizer tablet (optional).

CAMMS version 2.0 requires that the terrain data be provided in specific digital format. No provision for terrain map data preparation is provided in the system. Data processing done with CAMMS always includes and is limited to the specific map area provided in the data base. There are no GIS functions (i.e., to extract, overlay, or combine map data) provided with CAMMS. Zoom and pan of output display is provided but the area represented and content of the actual map data cannot be altered on CAMMS.

Products from CAMMS include (CAMMS user manual):

1) Soil Moisture Map (based on precipitation data)- shows area distribution of soil moisture based on historical weather data.

2) Terrain Factor Map- shows values of factors that strongly influence off-road ground speed- i.e slope, strength, surface roughness, vegetation spacing, and driver visibility.

3) Off-road Speed Map- shows speed for one or a mix of vehicles within a given terrain area and for a user-defined weather condition.

4) Off-road Reason Map- shows major reasons for speed limitations for a specified vehicle type within a given terrain area and for a user defined weather situation.

5) Off-road Difference Map- compares the off road speeds of the two user selected vehicle types within a terrain area and for a user defined weather situation.

Output and display consists of colored patch maps (for off-road data) and colored lines (for on-road) with the colors representing various selected terrain and prediction attributes.

The CAMMS system provides the powerful capability of analyzing the terrain's effect on mobility interactively for any combination of vehicles, terrain conditions, weather conditions, and operating scenarios. as a result, the terrain analyst has an infinite number of mobility "maps" available for use. CAMMS provides the simultaneous evaluation of on-road, off-road, and gap-crossing operations; coupled with the ability to incorporate weather conditions.

CONCLUSION

The focus of this paper has been in the historical setting through which military geography and terrain analysis have developed. Conflicts in the 50's and 60's helped to develop the Army's terrain analysis doctrine in the concept of terrain intelligence as a multiplier of combat power. Military laboratories, established since World War II, became actively involved in the quantitative aspects of military geography. When it was realized that terrain factors could be modeled and predicted with reasonable accuracy, the present Army terrain analysis program began. These concepts evolved through the 1970's until in the 80's the Army's terrain analysis was organized into units which are close to their principal customers/users: namely the tactical/maneuver commanders. The terrain products which are produced by these Terrain Teams are flexible and responsive to user's needs. However, it suffers from one major flaw: it is too slow.

Tomorrow's battlefield will be fast and constantly changing. As Sun Tzu wrote centuries ago:

> Conformation of the ground is of the greatest assistance in battle. Therefore, to estimate the enemy situation and to calculate distances and the degrees of difficulty of the terrain so as to control victory are virtues of the superior general. He who fights with full knowledge of these factors is certain to win;he who does not will surely be defeated. (Sun Tzu p128).

Army terrain analysis must be fast and flexible; computer assisted terrain analysis will be the key to meeting these needs. However, the terrain analyst must have manual backup capabilities when the computer fails.

MicroFix has demonstrated how vital computer assistance can be. TerraBase, the logical successor to MicroFix, can take terrain analysis further toward clear, fast, and accurate terrain products; and CAMMS, a sub-system for MicroFix and TerraBase, is needed by terrain teams who are already computer literate and understand the manipulation of digital data.

All of the research done so far have made tremendous contributions to the field of terrain analysis. However, the efforts have been of individual agencies and not a unified one. Agencies find themselves "competing" against each other to become the standard for the field and for funds. Enough research has been done, that it is time now for an unified effort to take place. This author believes that it is now time to unify all efforts under one agency (and funds) and set standards and priorities towards a standardized digital data base. The one agency in charge must incorporate the efforts from the others such as, United States Military Academy, the Waterways Experiment Station and the Engineer Topographic Laboratories; and it must also interface with probably the most important factor (and probably the most forgotten), the units in the field. In the field is where the real test of a system is accomplished.

The other suggestion or warning that this author would like to offer is that the terrain analyst must continue to be taught from a geographic base and not a computer science one. The terrain analyst of the future should not only be a keyboard operator, he must understand the factors of slope, vegetation, soils, surface drainage, lines of communication, obstacles, and water resources. The terrain analyst must know their effects combined and their importance separately. The human element in the terrain analysis process has been validated historically. Computers cannot replace the common sense approach of a well trained terrain analysis team. Computer algorithms cannot accomplish the many subjective decisions and explanations required in most terrain analysis. The exception to the "rules" that are not contained in the data base could spell disaster on the battlefield without the human intelligence to modify or qualify the synthesized results.

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