STATE-OF-THE-ART TERRAIN ANALYSIS CAPABILITIES FOR TODAY'S ARMY

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ABSTRACT

Army terrain teams are required to produce a wide range of tactical products to support combat operations. Computer-based systems make it possible to rapidly produce tactical products that previously could only be produced manually. The use of advanced software and hardware also adds a whole new range of analysis products and functions to the terrain analyst's repertoire. By integrating geographic information systems (GIS), image processing and data base management software together with scanning and communication technologies, the terrain analyst can "pull" existing data from appropriate sources, analyze the data to create products, enhance and/or create data as required, and "push" products and data back across the battlefield to other DoD systems. The Digital Topographic Support System/Quick Response Multicolor Printer (DTSS/QRMP) will provide quick and accurate tactical terrain analyses and digital topographic products in support of mission planning, decision making and combat operations that will greatly enhance the effectiveness of the Army in meeting its combat mission.

INTRODUCTION

Today's military forces face less well-defined threats than in previous years. A host of potentially dangerous adversaries exist throughout the world at any given time. The National Military Strategy of flexible and selective engagement requires the Army to maintain capabilities for missions involving peacetime engagement and conflict prevention, as well as to fight and win wars (The United States Army 1996 Modernization Plan, 1995). Modernization of today's Army is essential in order to compete on the battlefield of tomorrow. No matter how the threat changes, one thing that will not change is the importance of terrain in battlefield operations. Computer-based systems make it possible to rapidly respond to terrain analysis requirements.

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MISSION

Battlefield commanders rely heavily on a process called Intelligence Preparation of the Battlefield (IPB). IPB is an analytical methodology used to reduce uncertainties concerning the enemy, weather and terrain for all types of operations (FM 34-130, 1989). This process is initiated any time the commander faces a new enemy or receives a new mission. IPB analyses are most commonly used by the commander's operations and intelligence staff to support both defensive and offensive operations.

An integral part of the IPB process is terrain analysis. Terrain analysis consists of interpreting natural and man-made features of a geographic area, together with the influences of weather and climate, to determine their effects on military operations. This analysis must support IPB requirements at both the strategic and tactical levels of operation. Data at the 1:250,000 and smaller scales are used primarily to support strategic operations. This is considered to be high-level planning where commanders can obtain a broad overview of the battlefield. Tactical analysis is done at the 1:50,000 and larger scales of operation. It provides the commander with a much more detailed view of specific areas-of-interest on the battlefield.

Before they can analyze the military aspect of terrain, analysts must know the mission of the unit, type of operation, level of command, composition of the forces involved, and weapons and equipment involved (FM 5-33, 1990). Based on these needs, the analyst will create various tactical decision aids (TDAs) by integrating terrain data together with weather data and information obtained from maps and imagery. Examples of battlefield TDAs include: 1) observation and fields of fire, 2) cover and concealment, 3) obstacles, 4) key terrain and 5) avenues of approach.

Terrain analysts receive training in TDA production, as well as interpretation of topographic maps, aerial photographs and remotely-sensed imagery. TDA production is often a process of combining information from one or more terrain overlays. Available overlays include separate feature layers for vegetation, soil, slope, obstacles, hydrology and transportation. Manually combining feature attributes from several overlays is often a time-consuming, tedious procedure, especially in highly diverse areas. Making rapid updates to the data and creating new products is also very difficult using manual procedures. However, this type of analysis is ideal for computer-based systems.

COMPUTER-BASED SYSTEMS

The process of terrain analysis is evolving from a largely manual operation to one that relies increasingly on computer-based systems. The rate of this transition is rapidly increasing due in large part to changes in the DoD acquisition process, which requires the use of commercial-off-the-shelf (COTS) hardware and software whenever possible.

The availability of COTS hardware and software in turn creates the need for digital data to support computer-based systems. Data such as maps, overlays and imagery, once only available in hardcopy form, are now available in digital form for computer use in selected areas of the world. COTS software can also be used for dynamically editing and updating data as battlefield conditions change. It is also possible to create data to meet battlefield requirements. This may include new digital data for areas where none currently exists, or data at a scale or resolution not currently available.

It is extremely important for all battlefield systems to share a "common picture of the battlefield," meaning that all systems using digital data are using the same version of the data complete with any changes that have occurred. Advances in COTS hardware and software make it possible to easily "push" and "pull" data across the battlefield when sufficient bandwidth is available. Secure networks and communication devices ensure the integrity of the data being transmitted.

Another government initiative that is fueling the evolution to computer-based systems is the reuse of government-off-the-shelf (GOTS) software. Use of GOTS software eliminates the need to develop custom code to perform established functions. It also enables all systems that perform similar functions to use the same software, which eliminates varying results from different systems that perform similar functions.

DTSS/QRMP

The Digital Topographic Support System/Quick Response Multicolor Printer (DTSS/QRMP) is a computer-based system designed to help meet the needs of the terrain analyst in the 21st century. The DTSS/QRMP provides the terrain analyst with automated and semi-automated tools to perform functions required to support tactical combat operations. By leveraging the strengths of selected COTS and GOTS software packages, together with custom code, the end result is a faster, less expensive upgrade to the Army's everyday topographic support operations using state-of-the-art technology.

With the advent of computer-based systems, the range of products for which the terrain analyst has become responsible has increased from TDA production to creation of thematic overlays, intelligence overlays, image maps, 3-D perspective views and text reports. The analyst has also assumed responsibility for managing, updating, editing and, when necessary, creating the terrain data. In order to meet these requirements, the DTSS/QRMP integrates GIS (ARC/INFO) software to process vector data, image processing software (ERDAS Imagine) to manage raster data, GOTS software for selected terrain analysis functions, and custom code integrated into an easy-to-use graphical user interface (GUI).

Additional COTS hardware and software solutions have been found to enable the terrain analyst to "push" and "pull" information across the battlefield, scan hardcopy maps and imagery and remove grid lines from scanned images. Halftoning software is also provided to color match hardcopy output to the original source material. The system also has the ability to perform low-volume, large-format reproduction of hardcopy products, because no matter how digital the battlefield becomes, there will always be the need for paper maps. Access to these functions is also provided to the analyst by means of the custom GUI.

In addition to the GUI interface used to create required terrain analysis products, the analyst is capable of accessing native ARC/INFO and ERDAS Imagine software. This is especially useful if the analyst is required to preform analyses not currently provided for in the GUI software. However, the greatest strength of the DTSS/QRMP are the custom terrain analysis functions and the addition of image processing capabilities afforded to the terrain analyst.

ANALYSIS FUNCTIONS

The DTSS/QRMP custom terrain analysis functions consist of TDA production tools, the Graphic Topographic Library (GTL), the Source Data Editor (SDE), and data bases access software that outputs text reports. TDA production tools step the analyst through the production of various vector products. The GTL provides the analyst with a graphical tool to display and interrogate data resident on the system. The SDE provides tools for on-screen data base creation, modification and update. Data base access software provides the analyst with known environmental factors and bridge classifications. In addition to these custom terrain analysis functions, the DTSS/QRMP also provides the terrain analyst with image processing software to perform new imagery-related tasks. A detailed discussion of each of these functions will be presented in turn.

TDA Production Tools

TDA production tools provide the analyst with an interface to manage DTSS/QRMP projects and products. TDAs are grouped into four different types: Mobility, Intervisibility, Terrain Elevation and Special Purpose Products. Custom menus step the analyst through the creation of various products for each product type. Following production of TDAs, they can be viewed graphically and/or output using the Final Product Review tools within the TDA production environment.

Mobility The DTSS/QRMP mobility analysis function provides the terrain analyst with the ability to produce TDAs that depict relationships between terrain factors, weather conditions, and various military vehicle parameters. Mobility TDAs are created using the NATO Reference Mobility Model II (NRMMII), developed by the U.S. Army Waterways Experimentation Station (WES). Custom software

integrates GOTS NRMMII software with ARC/INFO to perform the required analyses.

A total of 14 different vector mobility products can be generated using the custom workflow provided by the Product Manager. Six of the products are related to off-road and on-road speed conditions. Off-Road and On-Road Speed products depict the speeds computed for an analyst-specified vehicle as determined from weather data, soil conditions, vegetation, slope and obstacles. Off-Road and On-Road Reason products graphically show the reason for certain NOGO speeds and limiting factors for particular Off-Road and On-Road Speed products. Off-Road and On-Road Comparison products are designed to show the differences between speeds for two different vehicles.

Two of the products, Surface Degradation and Trafficability, examine the effects of vehicular traffic on soil conditions. Surface Degradation creates a product that shows the depth of tracks made in the soil by an analyst-specified vehicle based on an analyst-defined number of passes made by the vehicle. Trafficability is designed to depict the total number of passes an analyst-specified vehicle can make over the soil before the vehicle becomes immobilized.

Gap Crossing products analyze vehicle/hydrology feature relationships. The results from Gap Crossing show the ability of an analyst-specified vehicle to ford, swim or span drainage features. A companion product, Gap Crossing Reason, portrays the reasons why a GO or NOGO condition exists for a particular Gap Crossing product.

Software is provided to create several products that perform route analyses. The Overland Route product shows the path of least resistance between two analyst-defined points, i.e., the path requiring the minimum time to traverse. The analyst selects whether roads can be used in the analysis or if it is limited to off-road travel only. On-Road Route products use the ARC/INFO NETWORK software to determine the best on-road route between two analyst-defined points. Mobility Corridors depict the best corridors of movement by analyzing Off-Road and On-Road predictions, obstacles and troop size.

The final product, Shaded Time Distance, depicts the amount of time it takes a vehicle to travel from the analyst-defined starting point to all other locations in the area covered by the data set. Shaded Time Distance products are created from existing Off-Road and On-Road Speed products for an analyst-specified vehicle. The analyst has the option of not including On-Road Speed if travel is to be limited to off-road only. The Shaded Time Distance product is used to generate the Overland Route product.

Intervisibility The TDA production tools for intervisiblity products use digital elevation data together with GOTS software to produce four vector products and

two profile plots. The vector products available to the analyst include Masked Area Plot, Target Acquisition, Flight Line Masking and Path Loss. The profile plots include Flight Line Target Locator and Terrain Profile.

Masked Area Plot displays areas around an analyst-specified site in which a target, at an analyst-specified altitude, is shielded from that site. Target Acquisition depicts the point at which incoming targets, at analyst-specified altitudes, first become visible to an analyst-specified site. The Flight Line Masking product shows areas of the terrain that are masked from the view of an aircraft following an analyst-specified flight path, when the line of view is perpendicular to the flight line. Path Loss depicts the effects of terrain and distance on a radio frequency signal, in terms of power of the signal, received at all locations within an analyst-specified area.

Flight Line Target Locator calculates the minimum altitude necessary for an aircraft to keep a specific target in view. Terrain Profile shows a profile view of the terrain from an analyst-specified starting and ending point. This is very useful to visualize a side view of the terrain. In order to account for the height of various terrain features, such as vegetation, the user has the option of adding feature height values to the raw elevation values when making the intervisibility products.

Terrain Elevation Like the intervisibility products, terrain elevation products also require digital elevation data as input. However, unlike intervisibility products that use the elevation data to produce site specific products, terrain elevation products are created by analysis for all the elevation values in the entire data set. Available terrain elevation products include Contours, Slope, Aspect, Elevation Tint, Shaded Relief and Terrain Perspectives.

The Contour product shows contour lines using an analyst-specified contour interval. Slope depicts polygonal groupings of slope ranges using either percent or degree values. Aspect is also a polygonal product that depicts the prevailing direction of slope, e.g., north facing, east facing, etc. Elevation Tint generates a polygonal banded elevation product at analyst-defined elevation intervals. This product is especially useful in generating other products that require elevation ranges as input. The Shaded Relief product depicts elevation values as a grayscale image using analyst-defined sun azimuth and altitude values. Terrain Perspective products are 3-D representations of the terrain surface over which imagery, digital maps or other TDAs can be draped.

Special Purpose Products Perhaps the most powerful analytical tool provided by the DTSS/QRMP is the Special Purpose Product Builder (SPPB). SPPB provides the analyst with tools to query vector data, as well as existing vector products, in order to create custom products required to support dynamic battlefield conditions. Analytic functions provided by SPPB include Data Query, Proximity Analysis, Smart Stacker and Product Stacker.

Data Query enables the analyst to define product categories by selecting the appropriate attributes of vector data that meet particular military scenarios. Output products depict such things as the best place to land helicopters or where to find construction resources for engineering purposes. The analyst can generate queries using attributes from the data specifications or use only those attributes present in the data being used for analysis. Queries can be saved for future use and can be used by other DTSS/QRMPs.

Smart Stacker is similar in function to Data Query, however whereas Data Query uses raw vector data as input, Smart Stacker uses existing products as input. Input can be any polygonal Mobility, Intervisibility, Terrain Elevation or SPPB product. The Smart Stacker functionality performs Boolean queries between existing product categories to create new output products and product categories. Using a Helicopter Landing Zone product from Data Query and a Masked Area Plot product from Intervisibility, an example output product might depict all helicopter landing zones in areas masked from the site location.

Two additional SPPB functions, Proximity Analysis and Product Stacker, are also provided to the analyst. Proximity Analysis provides tools to buffer vector data and existing product categories. An output product generated using Proximity Analysis might be all helicopter landing zones within 500 meters of primary roads. The final function, Product Stacker, allows the analyst to combine two or more products vertically and/or horizontally. Unlike Smart Stacker, which creates new categories from querying existing categories, a vertical Product Stacker product overlays ALL categories existing in ALL input products.

Final Product Review   Final product review consists of two steps -- Footprint and Finalize. Footprint provides the analyst with a GUI to build a standard map product through the definition of specific editable map elements. Symbology and scale can be changed in Footprint. Footprint also provides the analyst with the capability to stack vertically, subset the area and add an image background. Finalize generates a map product in ERDAS Imagine 8.2 Map Composition format as defined by the metadata provided by Footprint. The final product is displayed in the ERDAS Map Composer module. Finalize is also used to generate ERDAS plot files for hardcopy output.

Graphic Topographic Library (GTL)

The GTL is a cataloging tool used to track and interrogate geographic data on the system. This includes all source data, vector and raster, as well as interim and finished products. The GTL uses ArcView to display available data graphically in the form of geographic footprints depicted over a background showing country outlines. Individual ArcView themes can be enabled or disabled to display or hide footprints. Metadata associated with the data, such as the data type, is available in tables and can be interrogated using provided query tools. The GTL helps manage

data on the system and in this way data can be stored wherever the analyst feels is best.

Source Data Editor (SDE)

The SDE provides the analyst with the capability to generate new vector data layers, update existing vector data with new information obtained from imagery or intelligence sources, and otherwise modify vector layers as required. These data can be used to update digital map products, as well as input into mobility and SPPB product creation. The SDE uses a customized ArcTools interface together with attribute templates to facilitate editing and data base creation. Attribute templates that use plain text language descriptions are especially useful when attempting to edit or create complex data consisting of numerous possible features and attributes.

Within the SDE, ArcStorm is used for temporal data management. Data base edits are stored as historical transactions which can be viewed for authentication prior to distribution and/or use, ensuring that all battlefield systems have a "common picture of the battlefield." Administrative "checkpoints" are created to assist data verification following edits. Transaction management enables data to be restored to a prior state if required. The SDE enables hardware, software, and personnel resources to be flexibly allocated to update common data resources.

Data Base Access

Environmental Various climatic data bases, covering different environmental statistics, can be queried using GOTS software to generate text reports. Environmental Threshold and Impact reports can be generated by querying information that contains quantitative and qualitative statements regarding environmental effects on materiel, personnel and/or operations. The analyst can predict Sunrise/Sunset/Twilight and Moonrise/Moonset/Illumination for a specified date and location. Climatology reports can be generated from queries made against historical data bases, including Historical Climatic Statistics, Density Altitude Climatology, Surface Wind Climatology and Paradrop Climatology. Finally, the analyst can query for the maximum load-carrying capabilities of different helicopters for different temperatures and altitudes to generate a Helicopter Load Determination report.

Bridges GOTS software is used to generate text reports that list the capabilities of different bridge types to handle one-way and two-way tracked and wheeled vehicles and additional bracing requirements for vehicular traffic. Reports are available for five different bridge types, including concrete slab, concrete beam, masonry arch, steel and timber. The user is prompted for various input values, such as for span length and width, road width, and various other parameters associated with the particular bridge type of interest. Reports of this type are used

by the analyst to plan avenues of approach. Information gained from these reports can be added to the data base and used in subsequent analyses.

Image Processing

By including ERDAS Imagine in the DTSS/QRMP software suite, the Army has provided the terrain analyst with the capability to perform standalone image processing functions using raster data such as digital maps and imagery. These functions include image rectification and enhancement, as well as supervised and unsupervised classification. The Spatial Modeler function in ERDAS Imagine is a graphical modeling interface for raster model creation. Using Spatial Modeler, the analyst can easily create models for custom algorithms and functions that satisfy mission requirements. Image maps can be created easily and rapidly using the Imagine Map Composer.

FUTURE ENHANCEMENTS

Several software enhancements are planned for the DTSS/QRMP to make the system even more responsive to IPB requirements. Near-term enhancements, 1-2 years, include integrating real-time weather data collected on the battlefield with the mobility algorithms to provide a more dynamic product and incorporating tactical dam analysis software to examine dam breach and reservoir discharge effects on the terrain. Mid-term enhancements, 3-5 years, include more robust relational data base management and linking capabilities using Oracle software, as well as improved terrain visualization capabilities. Long-term enhancements, 5+ years, include leveraging research being conducted in the areas of automated feature extraction and artificial intelligence, as well as exploiting new data sources such as hyper-spectral imagery.

ISSUES

Use of computer-based systems by the military has created and/or reinforced several issues for the Army. An ongoing issue for the military is training and retaining competent personnel. Computer-based systems often require the user to be "computer literate," possessing a working knowledge of UNIX and one or more software packages. In most cases, much of the training required for system operation is acquired on-the-job and by the time the user becomes proficient at his/her job, he/she is often ready for reassignment or leaves the military altogether

Another issue is system maintenance and administration. The current Army personnel system does not possess a job series for this type of position. However, because of the proliferation of computer-based battlefield systems, this type of position is often a full time job for one or more people. The area of system

maintenance and administration also brings up the issue that no military training currently exists to meet this requirement.

Several issues revolve around data including availability, storage and metadata. Any computer-based system is only as good as the data that feeds it. Currently, very little vector data exists at the 1:50,000 scale to support tactical combat operations. It is probable that data will have to be rapidly created to support regional conflicts, however this data may only have minimum attribution requiring value adding in the field. This is why the DTSS/QRMP may rapidly evolve into a vehicle for data management, updating, editing and production in addition to its primary terrain analysis function.

As requirements for high resolution data increase, the issue of data storage becomes more important. Fortunately, commercial advances are rapidly being made in this area. However, the requirement to pass high resolution data electronically across the battlefield highlights the issue that current network capabilities are inadequate to meet this need. The issue of metadata, data about data, is in its infancy. No good guidelines currently exist for tracking data lineage and/or edits made to the data. However, with systems like the DTSS/QRMP capable of editing and creating data, this becomes a potentially major issue with no obvious answers.

CONCLUSIONS

Computer-based systems are being developed to support the rapid pace of battlefield operations. One such system is the DTSS/QRMP. The DTSS/QRMP provides the Army's terrain analyst with automated and semi-automated tools to rapidly create standard and custom-developed TDAs to aid the battlefield commander in the IPB process. TDAs produced using the DTSS/QRMP rely less on interpretation made by individual analysts, resulting in uniform products produced using accepted military standard operating procedures. In addition to TDA creation, the DTSS/QRMP provides the terrain analyst with the tools necessary to update, edit, create and manage data on the battlefield, as well as exploit imagery and intelligence data when available.

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