LARGE SCALE DIGITAL TERRAIN MODELING IN NORTH AMERICA

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Introduction

The technology of utilizing digital techniques in the topographic mapping process is not new. The U.S. Army Map Service (now part of the U.S.Defense Mapping Agency) converted topographic maps to digital form over 25 years ago. The method used was to simply record in computer compatible form a string of x, y coordinates of index contour lines for a particular map. These "digital terrain models" were then used to make the molds of the familiar raised-relief maps of mountainous areas in the United states.

The idea of reversing the process, i.e. creating contour lines from digital terrain models, instead of creating digital terrain models from contours, was a logical step that was soon successfully undertaken. Processes, techniques, and computer programs have been refined to the point where now an increasing percentage of small scale topographic mapping is being accomplished by digital methods by public and private mapping organizations in North America.

A key advantage to topographic mapping by digital methods is the wide variety of additional graphical and numerical products that can be generated or produced from the digital data. In fact, one may now think of the digital data file as the main product to be produced by the photogrammetrist, instead of the topographic map. The topographic map now sits alongside a wide assortment of other products derived from the digital file. Chief of these is probably the orthophoto, which cannot be produced without terrain information. Others are: the topographic map, maps of elevation, slope and aspect zones, profiles of lines, intervisibility maps and perspective plots.

The resection (or mathematically defining imaginary lines so they can be plotted onto an aerial photo in the true geometry of the photo) cannot be done without the digital model. The resection is being applied where the aerial photo is used as a field document, to locate imaginary lines on the ground such as clearing limits for road construction, property boundaries, new road centerlines, etc.

The true utility of the digital terrain model is only beginning to be tapped. The future will see increasing uses of this tool as the imaginations of mapping and engineering professionals, as well as those in other disciplines, are applied.

Large Scale Digital Terrain Modeling.

For purposes of this report, "Large Scale" refers to scales of 1:20,000 and larger, with appropriate contour interval. Maps at this scale are used for tactical planning and engineering design, where accuracy of the data is relevant for calculating quantities, etc. At these scale ratios a lot of factors that can be ignored in smaller scale mapping become significant, more so as the scale increases, for example, vegetative cover softens or obscures topographic micro-relief that cannot be ignored at large scale.

Scaled positional accuracy and interpolated vertical accuracy are of greater importance on larger scale maps used for engineering design purposes. This fact calls for instruments and procedures selected with this in mind.

Data Collection

For small-scale terrain modeling, data are typically collected by photogrammetric scanning of parallel profiles that are separated by an appropriate interval which depends on the roughness of the terrain. Another method used in gentler terrain is to collect elevation data at grid intersections. These methods are efficient and adequate for the low accuracy requirements of small-scale modeling. Moreover, these methods require simpler computer programs to process the data.

Because of different accuracy requirements, large scale terrain modeling often requires special terrain data collection techniques, especially in rough terrain. Contour following is perhaps the most straightforward of data collection methods for large scale models. In this method, the plotter operator merely follows the contour in the stereo model, recording x, y position at distance, time, or operator determined intervals. Postplotting of the topographic map requires no special processing of the data; however, the creation of a true terrain data file will require additional processing. Contour following is a method that will yield excellent accuracy and portrayal of microrelief. However, the method is slow and inefficient, because much unneeded data are collected.

Of the software systems used for griding and contouring of digital terrain data, most do not provide for special handling of terrain breaks. This is critical in rough terrain for Engineering projects. The graphics produced, though esthetically pleasing, should be used with caution. Terrain breaks can (and should) be collected with a special identifying code, even if the code is presently ignored. This will allow for benchmarking new systems, or remapping as the technology improves. The amount of data collected, and digitizing time, can also be reduced.

A more efficient means of collecting data is by pattern digitizing. In this method less data is collected than in any other, and it also enables the simultaneous classification of terrain features. Significant terrain features are digitized, such as breaks, ridges, drains, manmade works, etc. These are supplemented with only enough random terrain points to densify the data. As data are normally converted from digitizer inches or millimeters to ground coordinates in feet or meters, densification in areas of incomplete photo coverage or heavy vegetation can be accomplished by many methods, including plane table methods, or electronic stadia equipment. Most applications software do not care how the data were obtained - only that the coordinate system is consistent.

Validity checks

Some means of testing the fidelity with which the digital data represents the terrain is essential, if trust in the products is to be achieved. Field checks of topo maps have been used for years and are useful for digital models as well. Office procedures in which the positions of points derived from the terrain model are compared to points whose position is independently determined are less expensive and time consuming, and may, if proper procedures are followed, be just as valid as field checks. One such technique is to independently measure the x, y, z position of a large number of points by photogrammetry, then compare the z of the same x, y position with the z computed from the digital model. Statistical tests can then be applied to quantify the validity of the digital model.

Computer Processing

A number of computer programs are used to manipulate the digital data. For efficient data handling for graphic output, the data are most conveniently stored and processed in array (grid) format. Obviously, if the data are not collected in a grid format, they must be converted to grid. Most programs used to do this compute the elevation of the grid points by finding three points around the grid intersections, then interpolating the elevation from the surface formed by the three points. Contouring programs and others then use the grid elevations to interpolate the location of the graphic needed.

Errors in digital terrain data are often selfevident from topography plots. The plot will show spikes or holes in the terrain. Locating the specific bad points in the data file can be difficult, and will be facilitated by processing the data through special analysis programs, although there are situations where even this may not provide definitive answers. Problem areas frequently occur in the overlap between 2 models. This may be caused by coordinate transformation differences between models. The same difficulty can occur when data are merged, due to slightly different datums - causing conflicting elevation determinations in the same vicinity. Ideally, there would be no overlapping models, or need to add supplemental data to an exising file. Better algorithms are being devised to differentiate between terrain abmornalities (or microrelief) and errors in the data. The process still requires human intervention.

Survey of Organizations

A survey of selected public and private mapping organizations in North America was made for this report. The purpose of the survey was to look at the practice of large scale digital mapping by a representative cross-section of organizations. The survey revealed a surprising vitality and diversity to this activity. Some may think of this technology as fairly new, yet some nonmilitary organizations have nearly 20 years or more experience with terrain digitizing; first at small scale, later increasing scale with smaller contour interval following improvements in technique, computer programs and instruments. It is evident that hundreds of square miles of terrain are being digitized yearly in North America, with the collection of data suitable for large scale mapping. Scales range from 1:20,000 to as large as 1:480. The products are typically used for tactical planning and resource mapping at the smaller scales, and engineering design of highways, dams, etc., at the larger scales. Contour intervals (C.I.) range from 10 meters to 1 foot. Photo scales used for stereo plotting typically range from 1:80,000 for the small scale, large C.I. products to photo scales as large as 1:2400 for large scale, small C.I. products.

Besides the contour plot, other main products usually produced from the terrain data are profiles and cross-sections, although many organizations also produce perspectives, iso-slope plots, and other graphical products taylored to meet specific requirements of the project.

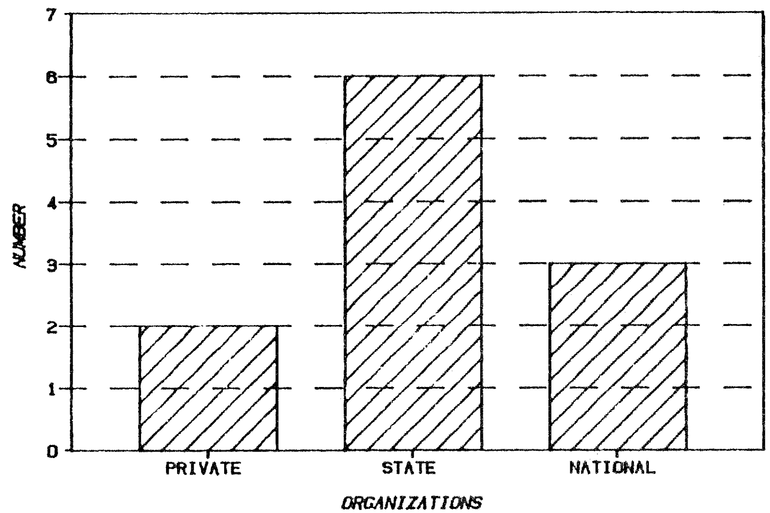
While some organizations no doubt still use projection type plotters encoded to collect x, y, z coordinates, the survey shows that optical train plotters generally are the preferred instruments. Analytical plotters are also being used, in those organizations with limited optical train capability. (It may be remarked that the use of analytical plotters for digitizing represents somewhat of an overkill.)

Digitizing productivity varies with terrain, photo and map scale, plotter and technique. Gentle terrain modeled at small scale using grid techniques can be modeled much faster than rough terrain modeled at larger scale using contour following, for example. Another factor affecting production is the amount of planimetric and cultural detail collected during digitizing. It seems that most organizations do at least some of this depending on other requirements. Production rates per month seem to run from 5-10 models per month on the slow end to 60 plus on the "fast" end. Production tends to be faster for small scale mapping, where attention to microrelief is not as critical.

The validity of the terrain model should be checked to allow confidence in the products derived from it. All organizations

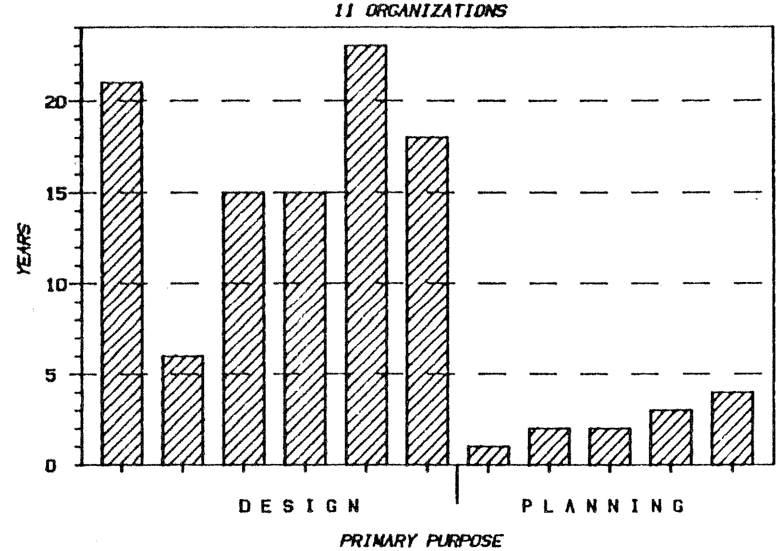
SURVEY ON DIGITAL TERRAIN MODELING

CATAGORY OF RESPONDENTS

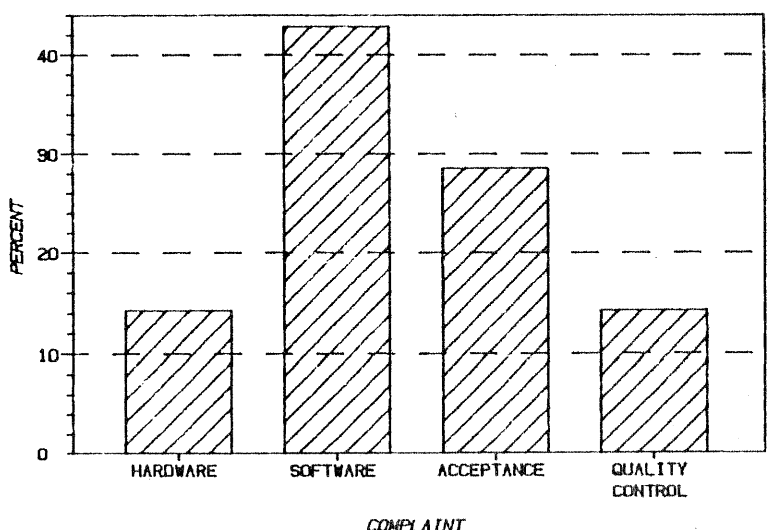


YEARS OF DTM EXPERIENCE

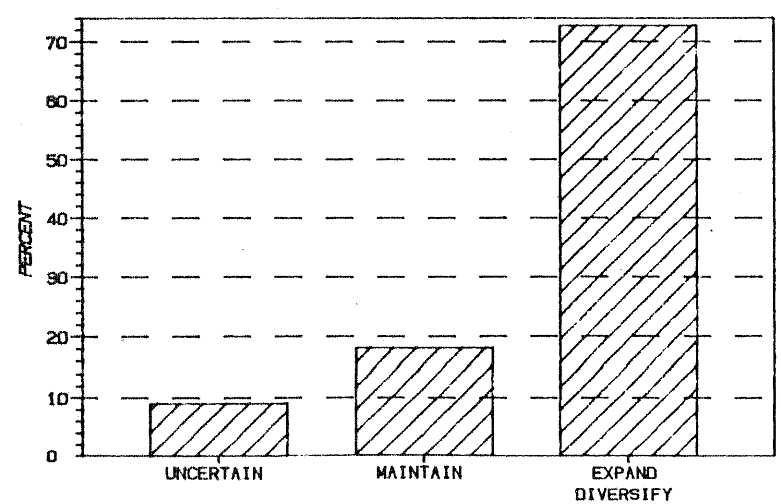
11 ORGANIZATIONS



BIGGEST PROBLEM ENCOUNTERED



FUTURE DTM PLANS



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surveyed routinely perform some sort of validity check, from simply comparing plots with known data, to extensive field checks. One technique deserving mention is the practice of independently measuring elevations of a statistically significant number of points, then comparing these points with elevations derived from the terrain model. The discrepancies are analyzed statistically by chi-square and other tests to show bias, and determine probable positional error. The points can be measured conveniently by photogrammetry.

Data files are normally collected onto disk or tape. (Cards are rapidly disappearing because of technological advances. They are not normally used for terrain digitizing because of the sheer volume of data. No organizations surveyed used cards.) If required, data are sent to satellite offices by tape, although a few larger organizations use telecommunications networks. Editing of data files is important to assure validity. All organizations surveyed perform an edit, most using online with CRT. Bad cells of data are replaced by merging files containing redigitized information.

Only the largest organizations have developed their own software for processing terrain data to produce graphical outputs. Usually these are Government organizations, which can afford the large front-end costs of this type of software development. Private organizations surveyed rely on Public Domain software or that purchased from vendors. Problems and modifications are dealt with usually by In-House expertise for Public Domain software, and reliance is placed on the vendor for support of their product. In-House computer expertise is a must for any organization engaged in collecting or processing digital terrain data.

Besides technical problems of software and hardware, another problem related to this technology and reported by government organizations is the acceptance of it by others within the organization. As with any "new" technological development, there is a lag between feasibility and wholesale acceptance by the community of potential users. As nearly always happens, the first attempts have problems to be worked out. Some overenthusiastic supporters often prematurely introduce the technology and overstate expectations of how it will perform. When the performance promised is not realized, early users get "soured" on the procedures and are doubly hard to persuade when the systems finally do work. In many cases it takes as long as a generation to fully implement or achieve widespread acceptance of new tools and techniques.

Typical Project Using Large-Scale Digital Terrain Data

A "typical" project using large-scale digital terrain modeling might be for engineering design for new highway construction. The route corridor would have been selected previously through a transportation planning process. Targeted field control points would be established and surveyed in the corridor, and other key points would also be targeted, e.g. boundary markers, points to be used for construction control, etc. Photography would be flown at 1:4800, bridged by semianalytical techniques and digitized with an optical train plotter. Digitizing of a strip centered on the road location would be a combination of raster scanning on the gentler terrain, supplemented with contour following on the rougher. In areas of closed canopy, terrain data would be collected by field methods, depending on terrain roughness, and merged with the data file. The data would be edited after a proof-plot to check for cells of bad or insufficient data. A contour plot at 1:1200 will be provided, contour interval will be 1 foot, 2, or 5 feet (1/2 m or 1m) depending on slope of terrain. A data file of roadway centerline profile and cross-sections will be furnished for roadway design of earthwork. Planimetric data will also be obtained, showing land boundaries, cultural detail, and natural features. Terrain data validity will be checked against points of known position, by office procedure. No extensive field checks will be made, providing the office check appears satisfactory.

The amount of planimetric and terrain information collected by this process simply <u>cannot</u> be duplicated by any other method at reasonable cost.

Future

All respondents were optimistic about the future of large-scale digital modeling. Growth in use is projected to occur as acceptance and familiarity increases among users. Trends seem to show greater use of analytical plotters, and improvements to computer programs to make them more operator friendly. They also indicate more innovative applications of the technology; e.g., close-range and terrestrial projects, and nontraditional applications such as for industrial problems.

Large scale digital terrain modeling may have suffered some of the growth pains we've seen in previous photogrammetric technology. However, we can be convinced that it has a bright future in North America. There is no other way currently known in which such vast amounts of geographic and terrain data can be collected and stored, and manipulated to produce such a variety of useful products, as cheaply and quickly as by this method.

APPENDIX I

Organizations Responding to Survey

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