*The Digital Terrain Model—Theory & Application**

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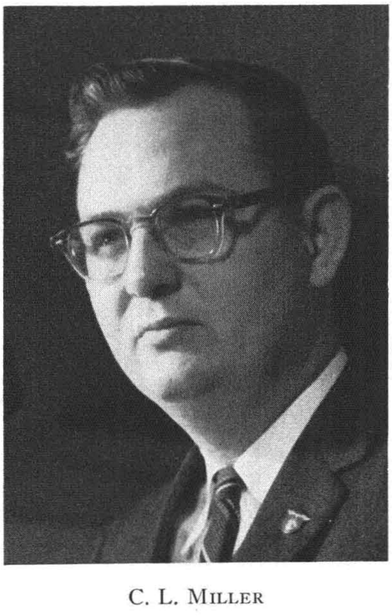
ABSTRACT: *In order to realize the full potential value of an integrated system of photogrammetry and electronic computers as applied to engineering problems, the concept of a digital terrain model has been developed oy the Photogrammetry Laboratory at the Massachusetts Institute of Technology. A band or area of terrain is represented in numerical or digital form from data taken from a contour map, or directly from the stereoplotter and stored on computer input material. The stored digital terrain model may be used to obtain numerical solutions to many types of terrain analysis problems by processing through an electronic digital computer according to programmed instructions. Such an approach enables the engineer to numerically evaluate an unlimited number of possible location, design, and other geometric solutions to the problem presented.*

INTRODUCTION

THE electronic digital computer can be applied to two major areas of application important to the photogrammetric engineer. The first is concerned with the reduction of the raw data (the photograph) to obtain the basic photogrammetric output (the spatial location of points). The computations associated with analytical space resection and intersection, aerotriangulation, transformations, and adjustments would be examples of the first area of computer application.

The second area of application concerns the computations associated with the solution of engineering, scientific, and military problems which involve the use of photogrammetric output data. The determination of highway earthwork, the determination of the change in the shape of a glacier, and the supplying of guidance instructions for a low level missile would be examples of a computer utilizing photogrammetric data.



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As a technical specialist, the photogrammetric engineer is primarily concerned with the first area of application. However, since these two areas are closely related, one giving direction to the other, they cannot be entirely separated. Stated more generally, an entirely new solution to a problem often comes from an integration of the technological advances made in many related or unrelated fields; also, consideration of the over-all problem from raw data to final answer will often lead to more efficient solutions.

During the last two years, the Photogrammetry Laboratory of the M.I.T. Civil Engineering Department has been conducting research on the subject of "new approaches to highway engineering through the application of photogrammetry, automation instrumentation, and electronic computers." The program is sponsored by the Massachusetts Department of Public Works in cooperation with the Bureau of Public Roads. The purpose of this paper is to describe one development by the project—the theory and application of the digital terrain model. Although it is primarily an advance in the use of the photogrammetric output, the implications to the practice of photogrammetry are important.

THE TERRAIN DATA PROBLEM

A convenient representation of the surface of the earth is a common requirement for many engineering, scientific, and military problems. The use and nature of terrain data storage and presentation forms such as the topographic map, the physical model, the three dimensional stereomodel, and the profile and cross-section are all common examples. These are all essentially analog forms of terrain data and are designed primarily for human interpretation and utilization in mental and manual processes. Obviously, many of the mental and manual processes for which the human utilizes such terrain data in obtaining numerical answers to problems can be efficiently handled by the electronic digital computer.

A fundamental requirement for using a computer efficiently is to have the terrain data in a form which the machine understands. In the case of the electronic digital computer, this form is of course digital data on computer input material such as punched cards, punched tape, or magnetic tape. Therefore, re-stating the first requirement, a machine data form counterpart of the engineer's topographic map or graphical cross section is needed.

Before the second requirement can be stated, certain characteristics of the modern computer should be examined. As everyone has heard, computers perform arithmetic operations at fantastic speeds. However, few people, even engineers, comprehend the significance of such computing speed on the impact the computers should have and will have in the approach to future problems. Such an impact is gradually being felt in the field of highway engineering where the initial efforts were to have the electronic computer do the identical work formerly handled by manual methods. Now that the "power under the hood" is being felt, radical changes in approaches can be expected.

One way to take advantage of the speed of the electronic computer is to numerically evaluate perhaps a hundred solutions to a problem where only one or two were considered previously. Another use for the speed is to take advantage of more exact and rigorous mathematical formulations of the problem instead of being limited to the simple approximations dictated by manual methods. Such changes in approach are economically justified as long as cost reflects a correspondingly more economical solution. For example, if a computer can determine a mile of earthwork in ten minutes at say $10 in computing cost, it certainly makes sense to spend 16 hours or $1000 in computing time if $10,000 can be saved in construction costs by a more economical location.

We now come to our second requirement for the efficient storage of terrain data. To take full advantage of the computer, our digital terrain data should permit the efficient consideration of a large number of possible solutions to the problem at hand and preferably more exact or correct solutions.

The digital terrain model system discussed in the remainder of the paper is one possible approach to realizing more of the potential value of photogrammetry and electronic computers in such fields as civil engineering.

THE DIGITAL TERRAIN MODEL

THE CONCEPT

The digital terrain model (*DTM*) is simply a statistical representation of the continuous surface of the ground by a large number of selected points with known *xyz* coordinates in an arbitrary coordinate field. Storing the *DTM* data on computer input material makes it available to the computer for an analysis of a wide variety of terrain problems, and also for the evaluation of an unlimited number of independent solutions to each type of problem.

THE COORDINATE SYSTEM

The origin and direction of *xy* horizontal axes of the *DTM* coordinate system and the *z* datum may be selected at will with due regard to convenience and the requirements of the particular problem at hand. This coordinate system is independent but should be related to an established system such as state plane-coordinates and mean sea-level datum. By arbitrarily specifying the *DTM* coordinates of two points of known state plane-coordinates, the state plane-coordinates of all *DTM* points may easily be computed, when required, using simple rotation and translation of axes formulae. Normally, the *DTM* datum will be mean sea-level or a parallel datum. For a given project, a number of different but related *DTM* coordinate systems might be used for different parts of the project area. In general, the engineer has rather complete freedom and considerable flexibility in selecting the most convenient *DTM* coordinate system.

DIGITAL REPRESENTATION SYSTEMS

The surface of the ground may be represented, in the *DTM*, by any one of a number of possible sets of selected points. The only requirement the set must meet is that it be stored systematically to facilitate recovery by the computer. This could be accomplished by specifying that the points be stored sequentially in order of increasing *x* (or *y* or *z*). Such a sequence might be used if a system of points such as used by the plane table topographer was selected.

By requiring that the points be located along a system of parallel scan lines, a more practical sequence of data results (Figure 1). Such scan lines will normally be lines of constant *x* (*y* scan lines) or lines of constant *y* (*x* scan lines). The distance between or spacing of the scan lines may be variable or constant, and the frequency of the points along the scan lines may be variable or constant. With constant spacing of the scan lines and constant frequency of points along the scan lines, a square or rectangular grid would result. Such a system would permit (1) the highest degree of automation in the data procurement phase, (2) the simplest processing of the data by the computer.

With a variable frequency of points along the scan lines, the selected points might be on (a) equal increments of *z* or contour line crossings, (b) increments corresponding to a constant product of *yz* increments, (c) terrain control points such as high and low points and slope breaks. Here again, the engineer has complete freedom in selecting the system of points best suited to the problem at hand. His choice might consider the type of terrain, available data procurement equipment,

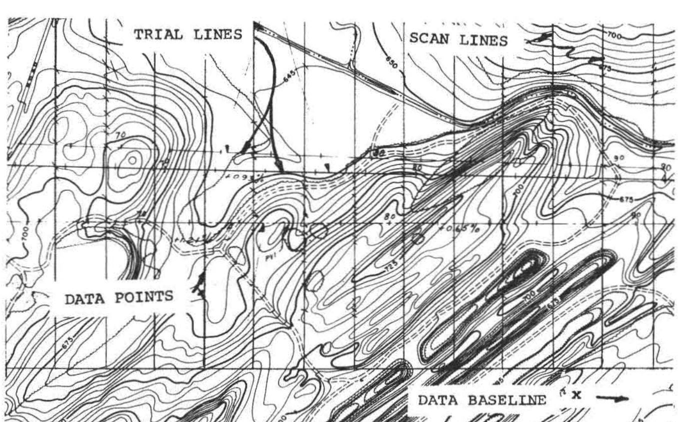

FIG. 1. This illustrates the arrangement of the Baseline, Scan lines, and Data Points. Data Points are shown at each contour line, but more or less points may be used as dictated by system requirements.

and the nature and requirements of his application of the *DTM*. In any of the systems, the density of the points for a given type of terrain will depend on the accuracy requirements associated with the application. Different applications will require different accuracy levels or degrees of permissive terrain approximation. In some engineering problems, a series of *DTM*'s with progressively higher densities of points for smaller areas might be advisable corresponding, for example, to the various stages in the location and design of a highway.

The Mathematical Terrain Model

The *DTM*, like the topographic map, uses a sample of data to represent the continuous surface of the ground. The *DTM* uses a sample of the infinite number of surface points, and the topographic map uses a sample of the infinite number of contour lines of the surface. Just as the engineer must interpolate on the topographic map, the computer will have to interpolate with the *DTM*. And in both cases straight line interpolation will often be quite satisfactory.

Since with the high-speed electronic computer, much more sophisticated interpolation with the *DTM* is quite practical, it is proposed that the actual model utilized by the computer be a mathematical model of the surface generated with the data furnished by the *DTM*. Instead of connecting each successive pair of points with a straight line, a third degree polynomial will be generated by the computer (Figure 2). A scan line will then consist of a number of continuous curves, each good for a specified range of y values. The equation for the section between y_2 and y_3 is of the form:

$$z = z_1 + A(y - y_1) + B(y - y_1)(y - y_2) + C(y - y_1)(y - y_2)(y - y_3)$$

where the constants are computed by the following equations in terms of the yz's of the four points bracketing the range of usefulness of the individual polynomial:

$$A = \frac{(z_2 - z_1)}{(y_2 - y_1)} \qquad B = \frac{(z_3 - z_1) - A(y_3 - y_1)}{(y_3 - y_1)(y_3 - y_2)}$$

$$C = \frac{(z_4 - z_1) - A(y_4 - y_1) - B(y_4 - y_1)(y_4 - y_2)}{(y_4 - y_1)(y_4 - y_2)(y_4 - y_3)}$$

By differentiating the equation of the polynomial, the slope at any point along the scan line may be obtained. By setting the differentiated form equal to zero, the location of the high and low points may be obtained. By integrating the polynomial, the area under the curve may be obtained. The following equations result.

$$\text{Slope } \frac{dz}{dy} = A + B[(y - y_1) + (y - y_2)] + C[(y - y_1)(y - y_2) + (y - y_3)(y - y_1) + (y - y_2)(y - y_3)]$$

$$\text{Area}_{y_2-y_3} = (y_3 - y_2)[Z_1 - Ay_1 - By_1y_2 - Cy_1y_2y_3] + \frac{(y_3^2 - y_2^2)}{2}[A - B(y_1 + y_2) + C(y_1y_2 + y_1y_3 + y_2y_3)] + \frac{(y_3^3 - y_2^3)}{3}[B - C(y_1 + y_2 + y_3)] + \frac{(y_3^4 - y_2^4)}{4}[C]$$

Interpolation between the scan lines may be accomplished in a similar manner by evaluating the polynomials across the scan lines and parallel to the scan lines which pass through the desired point from points previously interpolated on the polynomials along the scan lines. An alternate approach, and one which shows promise, is to evaluate the equation of a series of surfaces which will fit the *DTM* points. Considerable work is being performed on this subject but it has not yet reached a stage far enough advanced for reporting at this time.

The mathematical terrain model can be justified if the number of *DTM* points necessary to represent an area of interest can be greatly reduced. A single third degree polynomial might, for example, represent a given profile as accurately as would 50 straight line interpolations. (Figure 2) The speed and efficiency of the electronic computer permits one to think in terms of representing the surface of a project area by thousands or literally tens of thousands of mathematical equations.

DTM Data Instrumentation

The most important contribution of photogrammetry to the *DTM* concept is the practicality of obtaining the tremendous amount of terrain data necessary. It would be quite impractical to obtain the coordinates of, for example, 10,000 points in a one square mile area in any other way. Using photogrammetry,

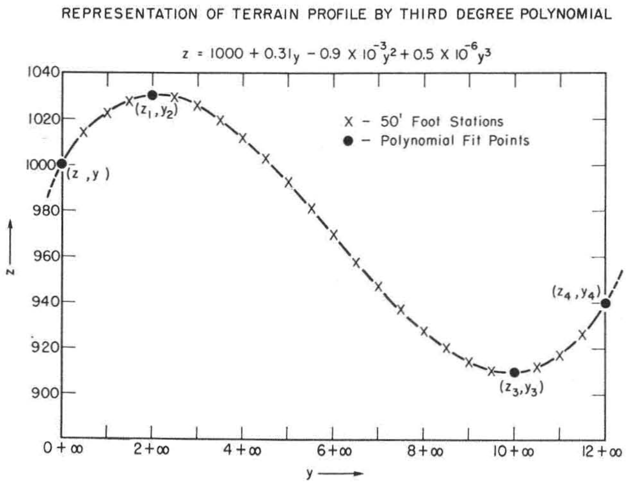

FIG. 2. This illustrates how terrain which would be represented by many points, using straight line interpolation, may be represented by fewer points using a third degree polynomial.

the data procurement problem is reduced to one of obtaining the coordinates of many points from the stereomodel in a fast, efficient, and accurate manner.

One approach to this problem is to prepare the standard topographic map to photogrammetric methods. The *DTM* data are readily obtainable from the contour map by graphically plotting the scan lines, manually scaling and recording the data, and manually punching the results. Such an approach has the advantage that a minimum additional investment in instrumentation is required—the price of a simple scale. For limited and special use of the *DTM* system, such an approach might be economical. However, the totally manual approach is of course the slowest and most costly in manpower expenses. It would not be practical for extensive use of the *DTM* concept. Two men, one scaling and one recording, will take about 200 points per hour on the average. Hence, our example of 10,000 points would take 50 hours at a cost of 100 manhours plus the cost of punching and verifying the results.

Semi-automatic scanning and output instrumentation for operation with a map as the source of data is quite possible and is the subject of current research and development at M.I.T. Several different approaches to the problem are being investigated and will be reported on at a later date. J. A. Stieber, of the U. S. Naval Training Device Center, is doing some related work on the procurement of digital data from maps to operate a numerically controlled milling machine for the production of physical terrain models.

A second manual approach to obtaining the *DTM* data would be to scale the data directly from the stereoplotter manuscript. Any of the systems of data along scan lines could be selected. With some plotters it is possible to plot continuous profiles across the stereomodel. This is being accomplished in the M.I.T. Photogrammetry Laboratory by means of a Nistri coordinatometer and coordinatograph unit, operating on either the Kelsh or Balplex plotter. These plots may then be digitized manually or automatically with a scanning and output system.

The first real step in automation of the data procurement is obtained by digitizing one or more of the x, y, and z scanning motions of the stereoplotter. If a rigid grid system is being used, it would only be necessary to digitize the z axis, the x and y positions being furnished by a projected or plotted grid. If the x increments are constant, and/or plotted, digitizing of the y and z axes would be sufficient. Complete flexibility and automation is only achieved by digitizing all three axes.

A basic requirement for a scanning system is that the scanning motions and the measurements they represent be converted to a form which can be digitized. This may be accomplished by converting the linear

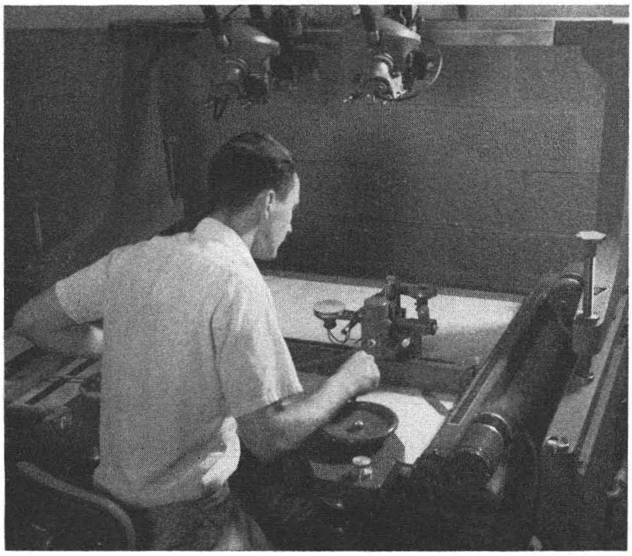

FIG. 3. The Nistri Coordinatometer shown on the Balplex Plotter. This unit is used to obtain the x, y, and z coordinates of points. It is also used on the Kelsh Plotter.

motions to equivalent shaft rotations by such means as a lead screw, rack and pinion, continuous wire or chain, or odometer type wheel. There are a number of commercial components for converting shaft rotations to digital output. A system of measuring and digitizing based on the use of a diffraction grating might also be used. A scanning, measuring, and digitizing system of unique design based on sending sound waves down a wire, has been developed by the Physics Department at M.I.T. for photographic data reduction and shows potential for stereoplotter application. As a matter of convenience, it is desirable to have the scanning axes parallel to the *DTM* data coordinate axes in order to directly read *DTM* coordinates. Therefore, either the stereomodel or the scanning unit axes should be capable of being rotated about a vertical axes.

For experimental work, the M.I.T. Photogrammetry Laboratory is using the previously mentioned Nistri unit as a three-dimensional scanning unit for double projection plotters (Figure 3). The unit is rotated in stereomodel space to align the axes.

An odometer type scanning unit for use with maps or plotters is being built. The Nistri unit may also be used for map scanning.

Two basic types of readout systems may be used. The slowest but simplest would be a static type, meaning that the operator must stop for each point, and press a button to accomplish the automatic readout and recording. Two such systems have been designed and are being developed in the M.I.T. Photogrammetry Laboratory, one using electronic counters (Figure 4) and the other, high speed relays. Although there are several commercial readout systems available which are adaptable to photogrammetry, the M.I.T. systems are being built to obtain a number of special experimental features for research work.

The second basic type of readout system which might be used would permit readout "on-the-fly" meaning that the operator could scan the model with a constant or variable but continuous drive. The coordinates of points at equal y, z, or yz increments would automatically be read out and recorded. Although the initial cost would be greater than for a static readout system, the increased speed would economically justify such a system in many cases. The actual data recording unit can take many commercial forms such as a tape punch, card punch, electric typewriter, magnetic tape recorder, or combination of such units.

The final degree of automation would be achieved by substituting an automatic scanning system for the human operator. We can also expect to see radical changes in the stereoplotter itself as more advan-

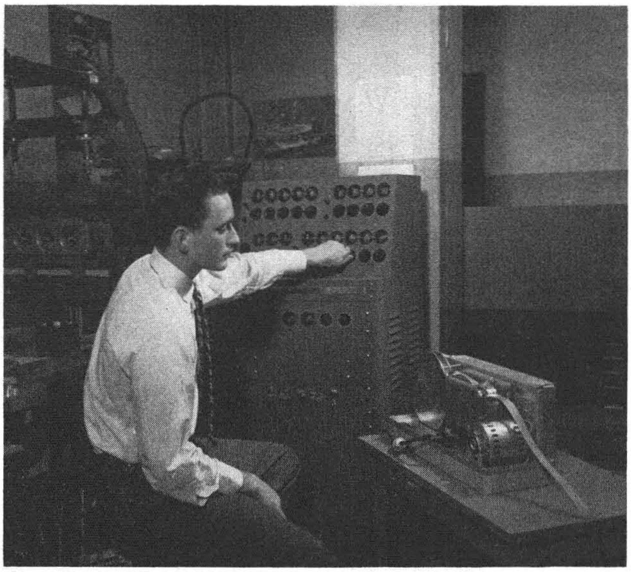

FIG. 4. The console, in the center of the photograph, gives a visual readout of the coordinates obtained from the Nistri Coordinatometer. The readout is by means of electronic counting tubes which also drive the Bendix tape punch, shown in the lower right-hand corner of the photograph.

tage is taken of the technological developments in automatic instrumentation. From the above paragraphs, it can be seen that the photogrammetric engineer has many possibilities for increasing the efficiency and speed of data procurement in conjunction with the *DTM* system. The M.I.T. research staff is concerned with the investigation of the over-all field of automatic instrumentation in photogrammetry with particular emphasis on highway engineering applications and is exploring many new possibilities in this direction. Since many other private, institutional, and governmental groups are working in the same and related fields, many new developments are anticipated.

ELECTRONIC COMPUTER OPERATIONS

With the *DTM* data or the mathematical terrain model data stored on computer input material, they may be read into internal computer storage in blocks as required. Hence, the represented surface is essentially available "on demand" at electronic speeds for operations by the computer. Most applications of the *DTM* are concerned with mathematically relating some spatial surface of interest to the *DTM* represented surface. The spatial surface of interest may be that of a proposed highway, the surface of a reservoir, or the path of a microwave. A series of mathematical equations must be written to represent the geometry of such surfaces in a three dimensional coordinate system which coincides with or is related to the *DTM* coordinate system. When this has been accomplished, a program is prepared to give the computer a set of instructions to follow in relating the two surfaces and computing the answers of interest.

Although each application of the *DTM* will have unique requirements and special controls on the necessary computer programs, there are a number of problems which are common to many applications. For example, the coordinates of the intersection of a given plane and the surface of the model is fundamental to the solution of many engineering problems. The intersection of a vertical plane and the model is a terrain profile; a horizontal plane and the model, a terrain contour; and a sloping plane and the model, perhaps the limits of a highway cut or fill. Such surfaces intersecting the model might also commonly be cylindrical or conical. Once the intersections of the two surfaces have been computed, a common problem is to determine the enclosed areas or volume. Hence, it is possible to write general computer programs which can be adapted easily to a wide range of applications.

Three basic electronic computer programs have been written at M.I.T. for applying the *DTM* to highway engineering. The Phase I program gives a general horizontal alignment solution for the problem of relating any alignment to the *DTM* data. The input data are the coordinates and radius of curvature at each point of intersection—the P.I.—and an origin of centerline stationing. The input data can be referenced to a coordinate system different from that of the *DTM* data and usually will be stated plane coordinates. The output of the Phase I program is the *DTM* coordinates and centerline stationing of selected points along the alignment, usually at stated intervals such as every 50 feet. The program also serves as a general solution to the profile problem, furnishing a terrain profile defined by the intersection of a series of plane and cylindrical vertical surfaces with the model.

The Phase II program gives a solution to the vertical alignment problem and relates the profile reference line of the highway surface to the *DTM* data. The input to Phase II consists of the station, elevation, and length of parabolic curve associates with each P.I. The output is the reference elevations at the same points computed in Phase I.

After the reference line for the proposed highway surface has been completely fixed in three dimensional space and related to the *DTM* data, the Phase III program generates the highway surface, computes intersections of the surface and the model, and determines the enclosed areas and volumes.

In the present program, the surface generated or the cross-section templet can be composed of a series of 20 planes, all of which are variable from job to job, and six of which are variables selected by the computer. Although these programs have immediate practical application to a variety of problems, they represent only the crude beginning of the programs which will ultimately be used with the *DTM*.

The programs described above require that the engineer specify to a great extent the shape and location of his surface of interest. In many cases it will be possible and desirable for the computer to assist in selecting the location of the engineering surface, according to limits and controls set by the engineer. An example would be a problem in which the computer is required to select the highway profile or grade line to meet specified optimization conditions and according to controls on gradient, curvature, sight distance, design practice, and similar geometric control specifications. Although the mathematical formulation and programming of such problems will be quite complex and costly, they are entirely practical and economically justified.

Multiple Variable Evaluation

The usefulness of the *DTM* approach can be greatly extended by simultaneously considering additional variables related to the problem at hand. This can be accomplished by attaching classification information and quantitative data describing other variables at each point. For example, the total data associated with each terrain point in the M.I.T. experimental work and automatically recorded by the output instrumentation take the form:

PPPP XXXXXX YYYYY ZZZZZ CCNN

comprised of four identification digits, six digits of the x coordinate, five of y, five of z, a classification and two digits of quantitative data. Six different formats of the output data are presently possible by means of a six position switch for different IBM card, Remington Rand card, and Bendix tape punch data formats.

The classification and quantitative data associated with a given point can take many forms and includes a number of different types of variables. For example, the classification might be the type of soil at the point, and the quantitative digits the depth of overburden to bedrock. Such data might be obtained by airphoto analysis and geophysical methods. The computer program using such *DTM* data would compute the volumes of each type of material included in the construction requirements. Alternately, the quantitative data might represent the unit right-of-way cost and the computer would be expected to determine the relative land acquisition cost for each alignment evaluated. The solution of the ultimate forms of such problems will be based on the digital cost model previously proposed by the senior author. In solving the problems, the computer will evaluate the most economical solution considering all cost and benefit variables. Admittedly, such problems become quite complex and have immediate practical restrictions but certainly should be the subject of active research.

Presentation and Utilization of the Output Data

The output of the electronic computer will be a digital or numerical form of data. Quite often the result of interest will be in the form of a numerical answer and no further transformation of the data will be necessary. However, in many cases the engineer will require an analog form of data presentation for human study. A graphical plot will be the most commonly used analog form.

Continuous line plotters are now available for graphically plotting the results of *DTM* problems. The potential applications of the *DTM* will call for a family of such plotters. For example, the output of the mathematical terrain model approach would call for a system which would permit plotting of the continuous third or higher degree polynomial equations defining surface profiles.

Note that the computer analysis of the mathematical terrain model could furnish output data for the plotting of contour lines either in terms of the coordinates of a large number of points on each contour or in terms of a series of equations defining each contour line. Such output could be automatically plotted to obtain contour maps of the *DTM* area.

An electronic computer program has been written by the M.I.T. Computation Center for plotting and recording a contour map of a matrix of digital values with the Type 740 Cathode Ray tube output recorder of the IBM type 704 computer. This program is being extensively used at M.I.T. in scientific data reduction and illustrates a number of possibilities in the engineering field. In addition to two dimensional continuous plots, the output data can be used for controlling three-dimensional cutting machines for carving physical models of the *DTM* area.

In all of the previous examples, the equations defining the engineering surfaces of interest will furnish the data for the plotting or carving of such surfaces along with the *DTM* surface. There are many other possible forms and uses for the output of the *DTM* system in solving engineering problems.

Résumé of Applications

A number of application examples have already been mentioned to illustrate characteristics of the *DTM* approach. A résumé of these and several other civil engineering areas of application follows.

a. Location, design, and quantity analysis for highways, railroads, canals, levees, dams, dredging, airports, building developments, etc.
b. Quantity determinations for borrow pits, quarries, open pit mines, coal and ore piles, and other types of manmade and natural cuts and embankments.
c. Surface change studies related to settlement, erosion, silting, etc.
d. Clearance studies for airport approach zones, microwave systems, radar and missile installations, etc.
e. Terrain analysis problems associated with reservoirs, drainage problems, transmission lines of all types, etc.

In essence it may be said that whenever two surfaces of interest are to be related and computations are required, the *DTM* offers a possible approach. Photogrammetry will usually offer the only practical approach to the problem of obtaining the required data, and the electronic computer makes it possible to consider computing problems which would require an army of men with desk calculators.

Acknowledgments

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O.M.I. Corporation of America, Bausch and Lomb. Finally, the authors pay tribute to their colleagues on the project staff including D. R. Schurz, E. P. Gladding, and T. H. Kaalstad.

References

Additional material on the subject paper will be found in the following publications of the M.I.T. Photogrammetry Laboratory.

1. No. 107—Preliminary Report, Integrated Aerial Photogrammetric and Electronic Computer System
2. No. 109—Digital Readout Systems and Components for Photogrammetric Instrumentation
3. No. 110—A Study of Directional Scanning Techniques
4. No. 111—Digital Terrain Model Approach to Highway Earthwork Analysis
5. No. 112—An Automatic Digital Output System for Double Projection Stereoplotters
6. No. 113—The Skew System for Highway Earthwork Analysis
7. No. 114—Electronic Computer Programming of the Skew System
8. No. 115—Earthwork Data Procurement by Photogrammetric Methods

Previous papers by the project staff which discuss some of the concepts presented in this paper include:

9. Miller, C. L. and R. D. Schurz, "Educational and Research Activities in Photogrammetry at M.I.T." PHOTOGRAMMETRIC ENGINEERING, March 1958.
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Information on developments by other groups which are related to the subject matter include:

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16. Stieber, J. A., "The Master Terrain Model System," paper presented at 1957 Joint Eastern Computer Conference. To be published in proceedings of conference.

B&L GLASS PLANT CELEBRATES 40TH ANNIVERSARY

This is an anniversary year for the Bausch & Lomb Optical Company of Rochester, New York. It marks 40 years of the successful manufacture of high grade optical glass for scientific, professional and industrial purposes. The story of optical glass in the United States begins at Bausch & Lomb early in the century, when William Bausch began experiments by mixing small batches of ingredients in an oil fired furnace which had been constructed next to the molding plant.

Beginning in 1917, the manufactur of optical glass in this country has been closely allied with national defense. Until 1917 all of the optical glass used in the United States was imported from Germany. By the end of 1917, the Bausch & Lomb Glass Plant had multiplied its volume by twenty times, and was manufacturing optica glass at the rate of 40,000 pounds per month At the close of World War I, B&L had produced 450,000 pounds, or 65% of all the optical glass used by the military forces. Twenty years later with the outbreak of World War II, Bausch & Lomb was again ready for military production. During the war, the Glass Plant manufactured high quality optical glass at about 1200% of the pre-war production.

Since 1918 B&L has continued to produce its own optical glass, and at the present time is the only manufacturer in the Western Hemisphere producing optical elements from sand to finished product. The requirements for the optical products made by Bausch & Lomb, including both ophthalmic goods and scientific instruments, numbers more than 120 different types of optical glass.

It has manufactured its own optical glass for years. Because the research experts have selected only the best raw ingredients and chemicals and the engineers and craftsmen control every operation in the processing, the Bausch & Lomb Optical Company has earned a reputation for the manufacture of optical glass of the very highest quality.