MAP—A *M*APPING AND *A*NALYSIS *P*ROGRAM FOR HARVEST PLANNING

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INTRODUCTION

The Northeastern Forest Experiment Station and the Department of Civil Engineering at West Virginia University are cooperating in the development of a Mapping and Analysis Program, to be named MAP. The goal of this computer software package is to significantly improve the planning and harvest efficiency of small to moderately sized harvest units located in mountainous terrain. The software package is to be implemented on the Experiment Station's Hewlett-Packard 9845 computer system.

The basic philosophy behind the development of the subject software package is to produce a user friendly system that will not only be easy to operate by harvest planners, with few computer skills, but will utilize input data that is relatively simple to acquire. The basis of the software system is to be a Geographic Information System (GIS) as described in (1). The most important component is a Triangulated Irregular Network (TIN) digital terrain model. The TIN is to be generated automatically using many of the software features described in (1). A major difference will be the use of field survey data instead of existing contour maps.

Several terrain modeling systems are available to the Forest Service for planning and management purposes. Examples are the TOPAS (Topographic Analysis System), DTIS (Digital Terrain Information System), MOSAIC (Method of Scenic Alternative Impacts by Computer) (2); and LANDFORM (Land Analysis and Display for Mining) (3). Each of these systems utilize digital terrain models in the form of a regular or irregular network of X-Y coordinates with assigned elevations. Although based on an irregular network terrain model, the MAP system is intended to be more comprehensive in its analysis capability. Unlike other modeling systems, MAP will not be limited in the type of data that can be input. In addition to terrain information, any spatial, linear or point data can be input using a simplified surveying technique. The uniqueness of the MAP system is the use of simple field survey procedures requiring only a

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compass, clinometer and tape. In spite of simplicity, the analysis capability of the system has the potential to be broadly applied in harvest planning. The method of MAP data base construction and its application are discussed in the following sections.

DATA BASE CONSTRUCTION

Data is input to MAP from field coding forms that are completed during a comprehensive survey of the harvest unit. The MAP data input software is designed to utilize a simplified form of survey information based on use of a survey compass, tape, and clinometer. The entire field survey of the unit relies on a systematic gathering of a series of bearing, distance, and percent slope measurements. These series of measurements are called a "traverse". While conducting a traverse the surveyor is provided with options of gathering additional information relating to area attributes, line or boundary types, and point or station classifications. Area attributes might denote the interior of the harvest unit as differentiated from areas external to the harvest unit; or, area attributes might be assigned according to forest types or environmentally sensitive areas within the harvest unit. Line or boundary information can be assigned along a traverse to identify linear features within the data base such as skid trails or area classification boundaries. The remaining possibility is a need to identify points or stations such as potential landings and tailholds. The following paragraphs illustrate the structure of this data base and its construction methodology.

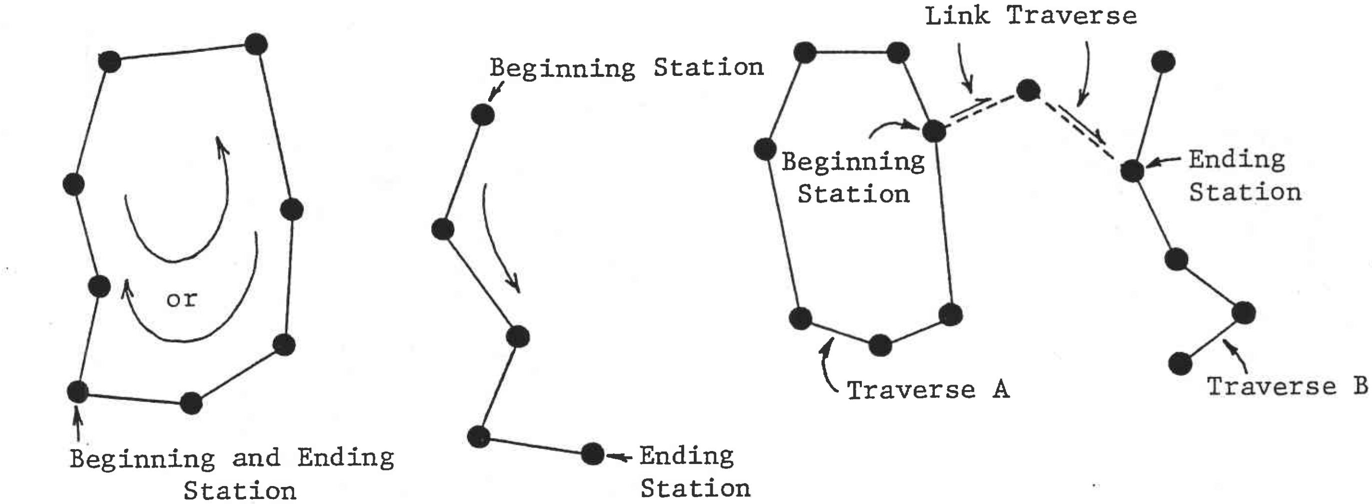
Traverses

The MAP data base structure originates as a systematic survey of the harvest unit. Most basically, all map-type data can be classified as area, line, or point data. A series of planned survey traverses can provide each of these data types, as needed, to fully map the area of interest. The survey traverse is defined as a series of bearing, distance, and percent slope measurements connecting a beginning station with an ending station. The traverse can be applied in any one of several different ways as illustrated in Figure 1.

The traverse must begin at a station and proceed to the next station in the traverse by specification of a bearing, distance, and percent slope. As illustrated in Figure 2, the bearing can be given as azimuth (0-360° clockwise from magnetic north) or as bearing from the north-south meridian (0-90°) in one of the four quadrants. Distance is measured as slope distance along the bearing to the next station. Slope is specified as a positive or negative value in percent, as appropriate. The stations are connected by "links" and the links are joined end-to-end in a sequential string until the traverse closes on itself, or is ended. Each station is identified by a unique number during the survey traverse. Link numbers are assigned automatically during computer processing of the data.

Regardless of the intended function of the traverse, line and point attribute data can be assigned to each link and station, respectively. The rules governing the completion of a traverse are minimal and can be listed as follows:

1. A traverse can be closed, but only to its beginning station.



a) Closed Traverse b) Open Traverse c) Link Traverse

Figure 1. Examples of Three Possible Traverse Types.

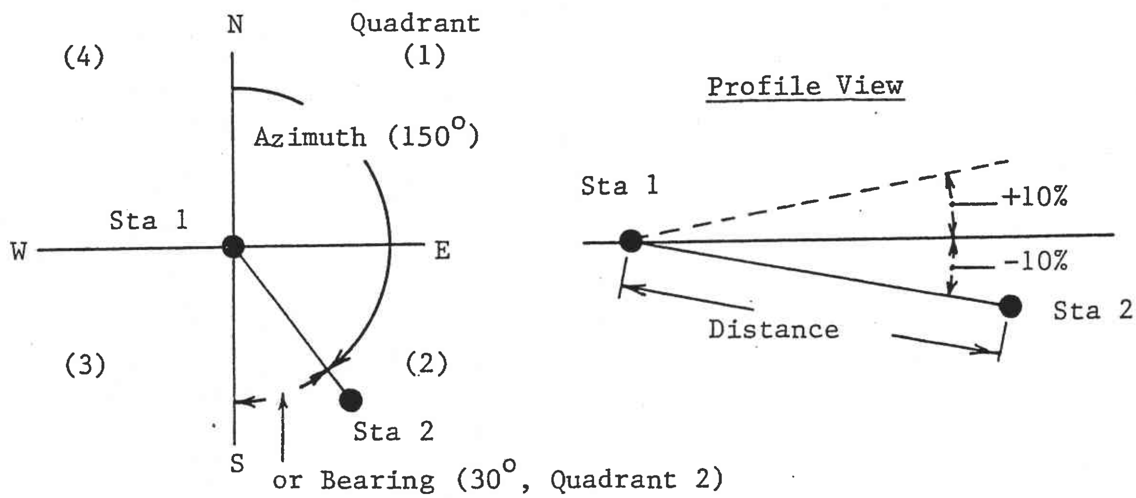


Figure 2. Example of Station to Station Measures of Bearing, Distance, and Slope.

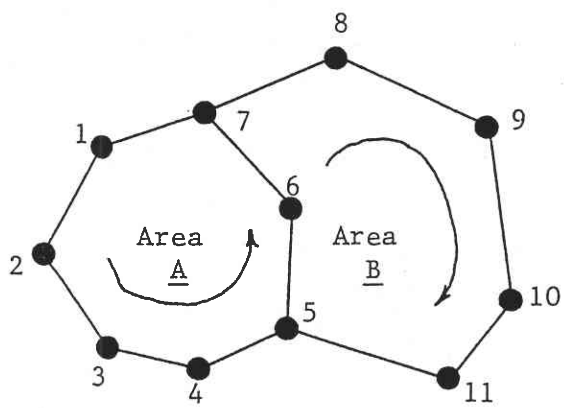


Figure 3. Assignment of Area Attributes in Closed Traverses

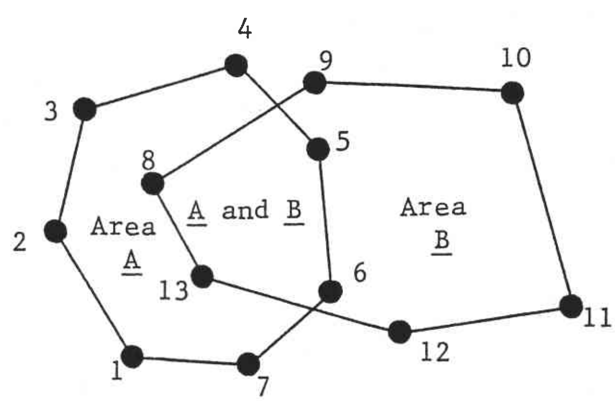


Figure 4. Illustration of Overlapping Closed Traverses

2. A traverse can share stations and links with other traverses as long as the original station numbers remain unique and unchanged.
3. The numbering of new stations must be sequential.
4. A traverse must consist of a continuous chain of links resulting from the bearing, distance and slope measurements taken from one station to the next.
5. A traverse cannot cross itself or contain a repeated station number. (Exception: the beginning and ending station number must be identical in a closed traverse).
6. To maintain data base connectivity, each individual traverse must share at least one station with another traverse within the data base.

As shown in Figure 1, traverses generally perform one of three functions. They enclose areas, represent linear features, or serve to connect two existing traverses. Also, any of the three types classified by Figure 1 can be used to locate point information. Each of these traverse types are discussed in more detail below.

Closed Traverses

A closed traverse contains a minimum of three links (3 stations) and must close to the beginning station without crossing itself. As shown in Figure 1 the traverse can be closed in a clockwise or counter clockwise direction. In general, the purpose of a closed traverse is to bound an area that has unique attributes. Therefore, an area attribute assignment is often made with respect to each closed traverse as shown in Figure 3. Since each traverse closes in a clockwise or counter clockwise direction, the inside and outside areas of the traverse are identified and the area attribute assignment can be associated with the enclosed area.

Each link and/or station around the traverse can be assigned attributes. Logically, links are assigned line or boundary attributes, and stations are assigned node or point attributes. Stations are assigned unique identification numbers, in sequential ascending order, at the time of the survey. No link identification numbers are assigned since each link can be identified by its beginning and ending station number. The attribute codes, if assigned, are in addition to the identification numbers.

Closed traverses can adjoin one another as shown in Figure 3 or they may overlap one another as shown in Figure 4. Area attribute assignments are made separately for each closed traverse. Overlapping closed traverses share a portion of the same area, and therefore, that shared area has more than one attribute assigned to it. Areas of shared attributes are assigned automatically by the computer software.

A specialized subset of closed traverses is defined to permit acquisition of terrain data. This latter type of traverse is called a DTM (Digital Terrain Model) traverse. The sole purpose of the DTM traverse is to create a relatively uniform array of coordinate-elevation points that serve as the foundation of the MAP data base structure. As illustrated in Figure 5, the traverses are of an approximate elongated rectangular form. They are used in multiples, aligned to a common direction, as required to fully cover the map area for which the total data base is to be constructed. Each elongated rectangle is closed to its beginning station such that station spacings, Δx and Δy, are on the average, approximately equal. Ideally, a rectangular

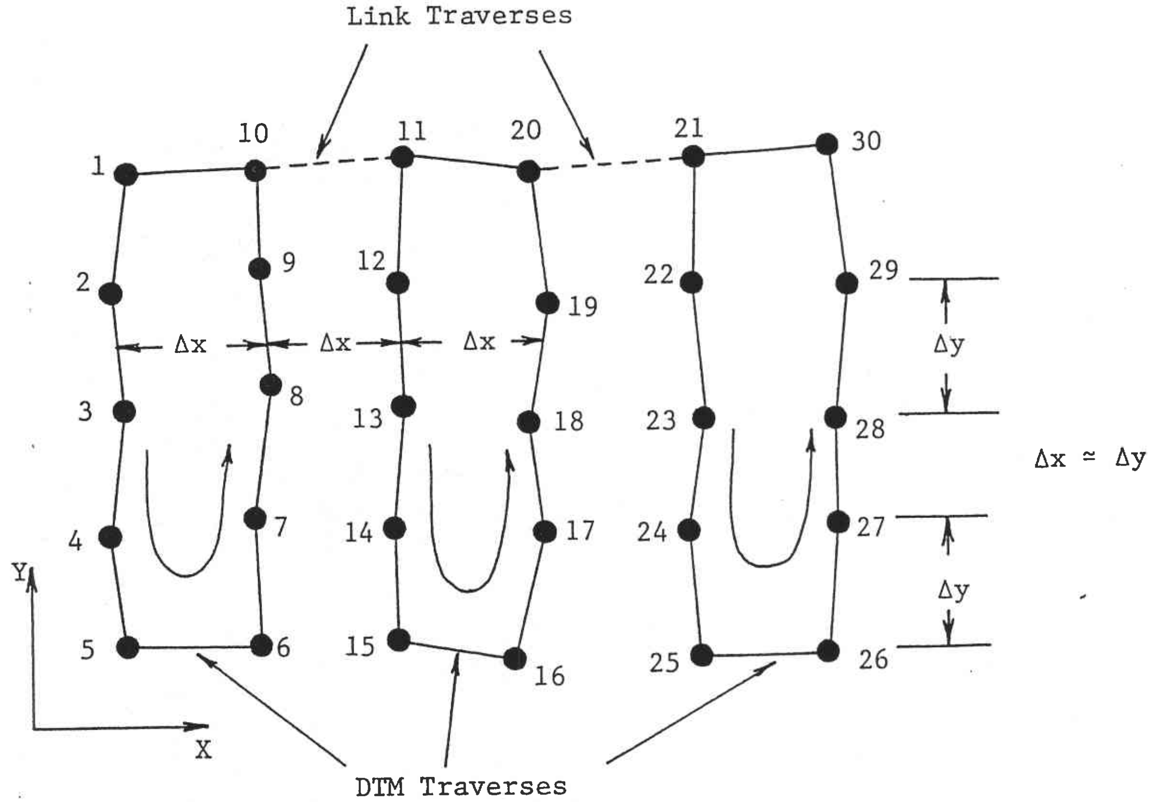
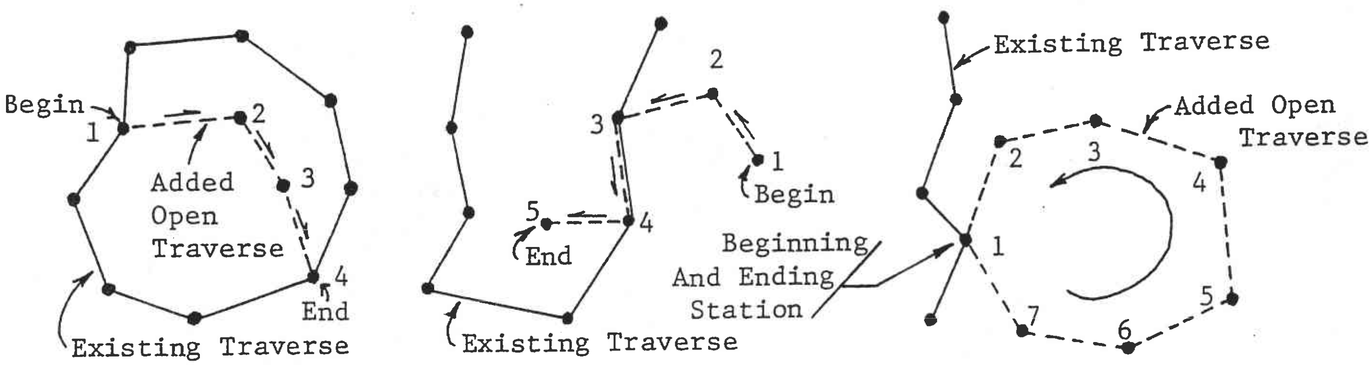


Figure 5. Configuration and Alignment of Digital Terrain Model Traverses.



a) Beginning and Ending on Another Traverse

b) Partial Sharing of Links

c) A "closed" Open Traverse Sharing A Common Station

Figure 6. Examples of Possible Open Traverse Use.

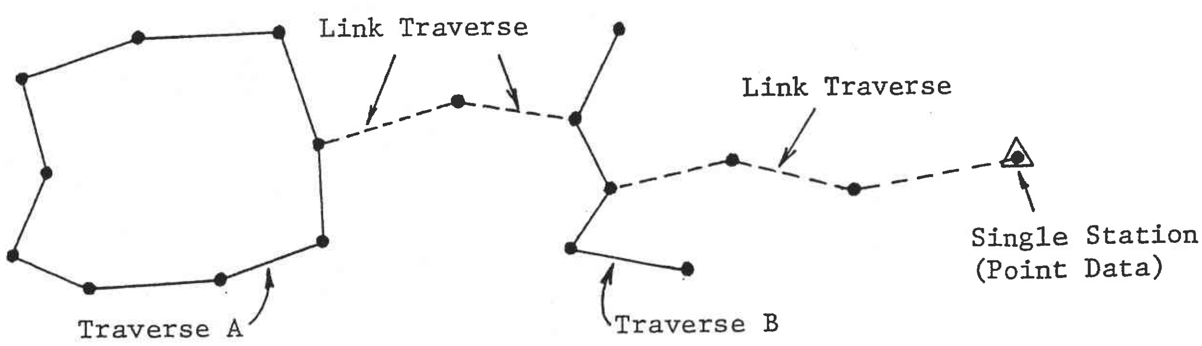


Figure 7. Examples of Link Traverse Application.

grid of stations spaced equally in Δx and Δy would result. However, the survey technique used does not permit this level of control. Since a triangulated irregular network (TIN) is used to interconnect the coordinate-elevation points, perfect control of Δx and Δy is not required. A DTM traverse is intended solely to construct the digital terrain model, and therefore, is not assigned attributes. Other than this limitation, all other rules regarding closed traverses apply.

Open Traverses

Closed traverses are for the purpose of enclosing areas or establishing the digital terrain model. Although each link in a closed traverse can be assigned attributes, line information is intended to be obtained by use of an open traverse (Figure 1). As befits its name, an open traverse does not enclose an area. It is a series of bearing, distance and slope measurements connecting a sequential set of stations along a linear feature. The traverse cannot cross itself, but may cross other traverses. Each open traverse can be assigned a line attribute common to all links in that traverse or attributes can be assigned to the links individually. The stations in the traverse can be assigned point attributes as before. The beginning and ending stations in an open traverse do not have to be common to another traverse as long as one of remaining stations is a common station. But it is permissible to begin and end an open traverse at stations common to another traverse (as shown in Figure 6). It may even begin and end at the same station. In this latter case the open traverse becomes a closed traverse, but without specification of a closure direction or assignment of an area attribute.

Link Traverses

Link traverses are a special application of open traverses for the purpose of connectivity and location of point data. It is not always convenient for a traverse to share one or more of its stations with another traverse to provide connectivity. In lieu of this direct connectivity, two traverses may be indirectly connected by a third open traverse, called a link traverse (see Figure 7). A link traverse is an open traverse used under more constrained conditions. Specifically, the beginning station of the link traverse is shared with one of the two traverses, and the ending station is shared with the remaining traverse. As shown in Figure 7, the link traverse can also be used to link a single free-standing station, of important attribute, to one of the traverses within the data base. Examples of single station data include landings, tailholds and bench marks. Although the link traverse application can include link attribute and point attribute assignments, as with any open traverse, there is little point in using the "link" label unless the traverse is primarily serving a "linking" function. If the traverse is performing multiple functions, then it would be more aptly called an open traverse.

Data Base Example

To illustrate the application of the proposed MAP software system, an example is presented. As shown in Figure 9, the field data acquisition format is relatively simple due to a common format for all traverses, regardless of their purpose. The data acquisition form is divided into two parts. The left side of the form records information pertaining to stations, while the right side records link information. The lines are staggered to emphasize

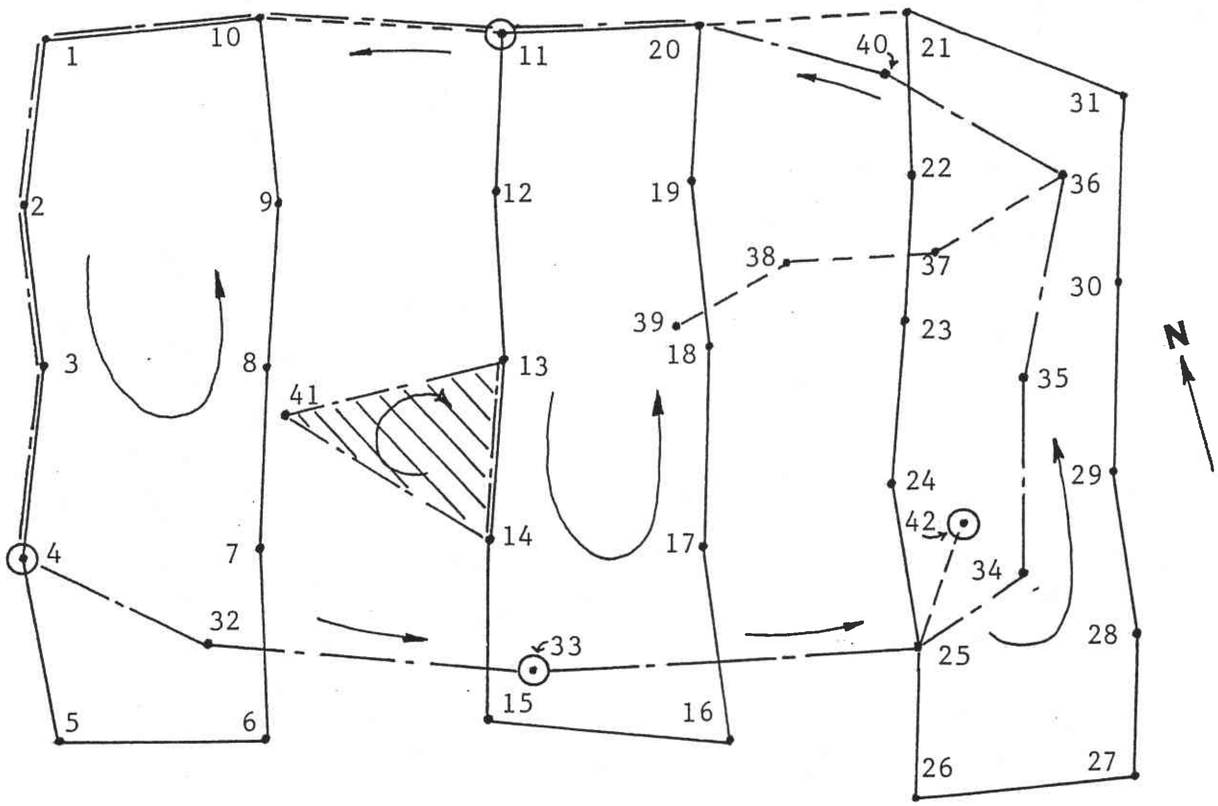


Figure 8. Example Harvest Unit Data Base

Triangulated Irregular Network (TIN) DTM

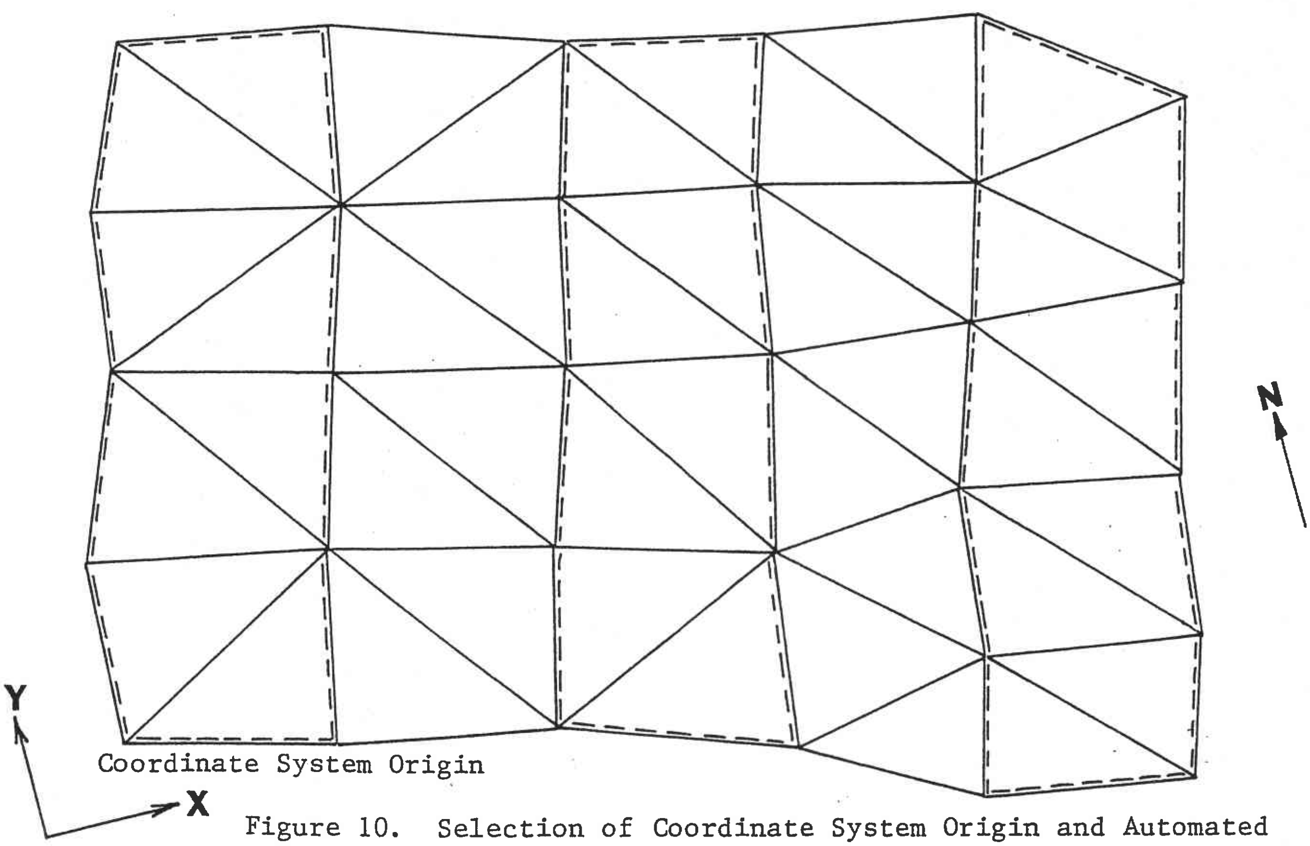


Figure 10. Selection of Coordinate System Origin and Automated Triangulation of Terrain Survey Stations.

the serial station-link-station order of data acquisition.

Since a traverse must begin or end at a station, the station line begins with the traverse beginning or ending code, B or E. The next entry on the same line labels the traverse type as DTM, closed, open or link. Following the traverse type is the station number. Although the station numbers need not be sequential along a given traverse, they must be sequentially assigned to each new station without skipping numbers. Station attribute codes are entered next, followed by the area attribute. The area attribute is required at the first station of a closed traverse. The link line is between and to the right of sequential station lines, since this information must be entered in traversing from one station to the next. The quadrant number is entered only if bearings are measured with respect to the north-south meridian. Following the bearing, distance and then slope are entered. Lastly, link attributes are entered. This process is continued until the traverse closes or is terminated at the ending station.

To illustrate the use of the data acquisition form, the example harvest unit survey shown in Figure 8 is coded in Figure 9. To properly survey a forest harvest unit, the total data base area must be bounded so that the digital terrain model (DTM) can be constructed covering this area. The DTM traverses are required to fully cover the study area so that all other traverses lie on or within the outer limits of the terrain model. The DTM traverses are completed first. As shown in Figure 8, the first DTM traverse is completed using 10 stations. Table 1 summarizes the station sequences for each traverse. In Figure 9 it will be noted that a possible tailhold location is coded at station 4 by the attribute number 3 (line 4S). Table 2 identifies the attributes assigned in this example. The first DTM traverse is closed back to station 1 using the end code, E (line 11S). The second traverse is a link traverse for the purpose of linking the first DTM traverse to the second. This link traverse has one link from station 10 to station 11. Station 11 initiates the second DTM traverse (line 14S) which utilizes stations 11 through 20. It will be noted that station 11 is also a landing site, coded with the appropriate attribute in the previous link traverse. This latter attribute code could have been assigned during the second DTM traverse. Station or link attributes can be assigned at any point where those elements are encountered in the coding process.

The second DTM traverse illustrates the ability to nest one traverse within another. That is, a given traverse can be halted at some intermediate point and a new traverse begun. On line 18S a nested traverse is initiated at station 14. The second DTM traverse within which this new traverse is nested is temporarily halted until the new traverse is completed. This concept is directly analogous to nesting do-loops in a computer program. The inner traverse is a three link closed traverse for the purpose of inclosing an environmentally sensitive area. Link 13-14 (line 20L) of the inner traverse is shared with link 13-14 (line 16L) of the outer DTM traverse. Since the bearing information has already been provided, line 20L is left blank except for any additional attribute codes. Line 21S closes the inner traverse and control returns to the outer DTM traverse. The DTM traverse is closed on line 28S at station 11. The third DTM traverse is coded in the same manner as the first two.

The harvest unit boundary traverse begins on line 43S, station 1. The first three links repeat links already established, and therefore, directional

Figure 9. Field Data Form Format Using Examp. Harvest Unit in Figure 8.

	Begin or End Traverse	Traverse Type (See Table 1)	Station Number	Station Attribute Codes (See Table 2)	Area Attribute
1S	B	DTM	1		
2S			2		
3S			3		
4S			4	3	
5S			5		
6S			6		
7S			7		
8S			8		
9S			9		
10S			10		
11S	E	DTM	1		
12S	B	LINK	10		
13S	E	LINK	11	2	
14S	B	DTM	11		
15S			12		
16S			13		
17S			14		
18S	B	CLOSE	14		2
19S			41		
20S			13		
21S	E	CLOSE	14		
22S			15		
23S			16		
24S			17		
25S			18		
26S			19		
27S			20		
28S	E	DTM	11		

	Bearing: Quadrant Number	Bearing: Degrees	Bearing: Minutes	Distance, ft	Slope, ±%	Link Attribute Codes (See Table 2)
1L	2	29	20	80	-10	
2L	2	20	11	75	-12	
3L	2	35	05	110	-8	
4L	2	10	18	100	-6	
5L	1	02	28	112	1	
6L		31	46	118	6	
7L		40	22	91	8	
8L		36	18	85	12	
9L		20	32	82	10	
10L	2	28	12	122	-1	
11L						
12L	1	02	52	116	1	
13L	2	15	32	101	-10	
14L	2	10	16	105	-11	
15L	2	01	35	106	-9	
16L	2	15	26	112	-8	
17L						
18L	3	10	36	130	6	4
19L		96	10	98	2	4
20L						4
21L	2	01	16	89	-8	
22L	1	15	41	122	-1	
23L		25	06	102	6	
24L		35	12	108	8	
25L		21	25	82	10	
26L		28	13	75	12	
27L	3	02	31	92	-1	

Figure 9. cont'd

	Begin or End Traverse	Traverse Type (See Table 1)	Station Number	Station Attribute Codes (See Table 2)	Area Attribute
29S	B	LINK	20		
30S	E	LINK	21		
31S	B	DTM	21		
32S			22		
33S			23		
34S			24		
35S			25		
36S			26		
37S			27		
38S			28		
39S			29		
40S			30		
41S			31		
42S	E	DTM	21		
43S	B	CLOSE	1		1
44S			2		
45S			3		
46S			4		
47S			32		
48S			33	3	
49S			25		
50S	B	LINK	25		
51S	E	LINK	42	3	
52S			34		
53S			35		
54S			36		
55S	B	OPEN	36		
56S			37		

	Quadrant Number	Bearing: Degrees	Bearing: Minutes	Distance, ft	Slope, ± %	Link Attribute Codes (See Table 2)
28L	1	00	22	98	-1	
29L						
30L	1	95	16	92	-10	
31L	2	01	37	72	-8	
32L	1	92	46	96	-11	
33L	2	12	21	98	-10	
34L	2	23	41	82	-9	
35L	1	01	08	101	-2	
36L		34	11	62	9	
37L		24	16	82	9	
38L		38	44	97	11	
39L		45	19	105	12	
40L	3	10	48	127	5	
41L						
42L						1
43L						1
44L						1
45L	1	62	51	101	-9	1
46L	1	72	09	152	-4	
47L	1	35	27	192	-2	1
48L						
49L		62	21	51	6	
50L		75	16	48	5	1
51L	1	06	24	105	7	1
52L		34	32	101	10	1
53L						
54L	2	10	16	58	-5	2
55L	2	81	32	68	1	2

Figure 9. cont'd

	Begin or End Traverse	Traverse Type (See Table 1)	Station Number	Station Attribute Codes (See Table 2)	Area Attribute
57S			38		
58S	E	OPEN	39		
59S			40		
60S			20		
61S			11		
62S			10		
63S	E	CLOSE	1		
64S					
65S					
66S					
67S					
68S					
69S					
70S					
71S					
72S					
73S					
74S					
75S					
76S					
77S					
78S					
79S					
80S					
81S					
82S					
83S					
84S					

	Bearing: Quadrant Number	Bearing: Degrees	Bearing: Minutes	Distance, ft	Slope, ±%	Link Attribute Codes (See Table 2)
56L	2	35	11	46	-2	2
57L	3	20	40	116	5	1
58L	3	01	28	100	4	1
59L						1
60L						1
61L						1
62L						
63L						
64L						
65L						
66L						
67L						
68L						
69L						
70L						
71L						
72L						
73L						
74L						
75L						
76L						
77L						
78L						
79L						
80L						
81L						
82L						

Table 1. Traverse Station Survey Sequence (Figure 9. Example).

traverse	type	Station Sequence	Traverse Purpose
1	DTM	1-2-3-4-5-6-7-8-9-10-1	Digital Terrain Model
2	Link	10-11	Link two DTM's
3	DTM	11-12-13-14-15-16 17-18-19-20-11	Digital Terrain Model
4	Link	20-21	Link Two DTM's
5	DTM	21-22-23-24-25-26-27-28-29-30-31-21	Digital Terrain Model
6	Link	25-30	Link Harvest Boundary to Tailhold
7	Open	36-37-38-39	Locate skid road
8	Closed	13-14-41-13	Inclose Environmentally Sensitive Area

Table 2. Example Station, Link, and Area Attribute Codes

Point	Line	Area
1 - Bench Mark	1 - Harvest Unit Boundary	1 - Harvest Unit
2 - Landing	2 - Skid Road	2 - Environmentally Sensitive Area
3 - Tailhold	3 - Power line	3 - Rock Outcrop
	4 - Boundary of Environmentally Sensitive Area	4 - Swamp
	5 - Rock Outcrop Boundary	

information is not supplied in lines 42L, 43L, and 44L. Note, however, that new link attribute information is added denoting the boundary characteristics. Station 33 on the harvest boundary is a potential tailhold, requiring the appropriate attribute code on line 48S. Continuing around the boundary traverse, a nested traverse is encountered at station 25, line 50. This latter nested traverse is a link traverse for the purpose of locating the tailhold at station 42. After returning to the boundary traverse, another nested traverse is encountered at station 36 (line 55S). This open traverse locates a skid road and requires 4 links. The boundary traverse ultimately closes back to station 1 using three links already identified (lines 59L, 60L and 61L). This completes the example as coded herein. It should be understood that the data illustrated in Figure 8 could be coded in many different ways. Another example might not include nested traverses. The traverses could be coded sequentially. The provision for nested traverses is for the surveyor's convenience, allowing the temporary interruption of a traverse in progress to include adjacent data.

COMPUTER PROCESSING

The MAP program is being implemented on the Hewlett-Packard 9845 computer system, using the HP Basic language. Since the 9845 is a dedicated stand-alone system, it can conveniently be used in the interactive mode. The MAP software is to be interactive, with graphics products being available at the intermediate steps.

Following completion of the field survey, the data forms (Figure 9) will be returned to the computer site for data entry. The computer operator first builds a data file that is very similar to the format of the field data form. The information will be entered in the same sequence from beginning to end using the computer's key board.

After the input data file is built, the MAP program is initiated and it reads the input data file, producing internal files of nodes and connecting links for all of the traverses. Attribute files are also maintained in a manner that connects them with the appropriate components. The coordinate system origin is automatically selected in the lower southwest corner of the data base so that all data base coordinates are positive numbers (see Figure 10). Since the digital terrain model (DTM) must bound the data base, the DTM traverses are used to establish the origin and the maximum coordinate limits. A provision will be made to allow optional manual selection of the origin.

Processing of the input data begins with the conversion of the bearing, distance and slope format of the DTM traverses to a X-Y-Z coordinate format, with Z being estimated elevation above sea level. The Z datum is established by entering an elevation estimate for one of the DTM traverse stations. Since the DTM traverses are closed traverses, survey error corrections are accomplished first for each traverse. If no bench mark station is specified within one of the DTM traverses, the first station in the first traverse is assumed to be the bench mark and all error corrections are made with respect to this station. The remaining DTM traverses are closure corrected and the station coordinates established with respect to the first traverse.

A triangulated irregular network (TIN) terrain model is created automatically in software as shown in Figure 10. The triangular elements simulate the topography of the harvest unit as a surface of triangular facets, as illustrated by the perspective view example shown in Figure 11. The terrain model contains the majority of the basic information needed to feed logging analysis routines. The remaining traverses define boundaries, linear features, and point information pertaining to the proposed harvest unit and its logging system design. Each traverse is processed in turn by transformation to the rectangular X-Y-Z coordinate system of the digital terrain model. At completion, all stations contained within the data base are referenced to the same coordinate system such that the various traverses can be treated as overlays, one on top of another. This commonality permits computations of many map measures of interest to the harvest planner. The following section discusses some of the possible applications of MAP.

APPLICATION TO LOGGING SYSTEM ANALYSIS

The MAP input data processing routines convert all traverses to a common rectangular coordinate system. The resulting common data base then is available for analysis computations. The computations can produce area, length, and slope measures which are intermediate to more complex application analyses, or can be produced as final output. Examples of final output quantities include:

1. Harvest unit perimeter length,
2. Harvest unit area,
3. Horizontal and slope distances from landings to potential tailholds, or from landings along potential skid roads,
4. Ground profiles along cableways and skid roads,
5. List of elevation data by profile and station,
6. Maps of the cutting unit area with contours,
7. and payload analysis for corridors of interest.

CONSIDERATION FOR USERS

The proposed mapping and analysis methodology should provide the logging research and applied industry with a much needed harvest planning tool. The MAP mapping and analysis system requires simple input and should be quite easy to execute. Although the inner workings of the software package appear to be quite complex, this complexity is not seen by the user and he need not be concerned with anything other than entering data and receiving output. The output in the form of unit maps, although simple, would provide most of the terrain and other pertinent information required for most harvest planning.

In order to describe the detail inner workings of the MAP software package, the discussion within this paper may appear cumbersome and complicated. This latter problem is unavoidable in order to discuss the basic model structure and execution. The actual use of the program will be much simpler and more extensively documented. We plan to have the package done and available within 1 year of this paper. Although it is not envisioned that a program such as MAP would provide all the answers to harvest planners, it should provide a simple, inexpensive harvest planning tool. This tool will hopefully result in better decisions being made.

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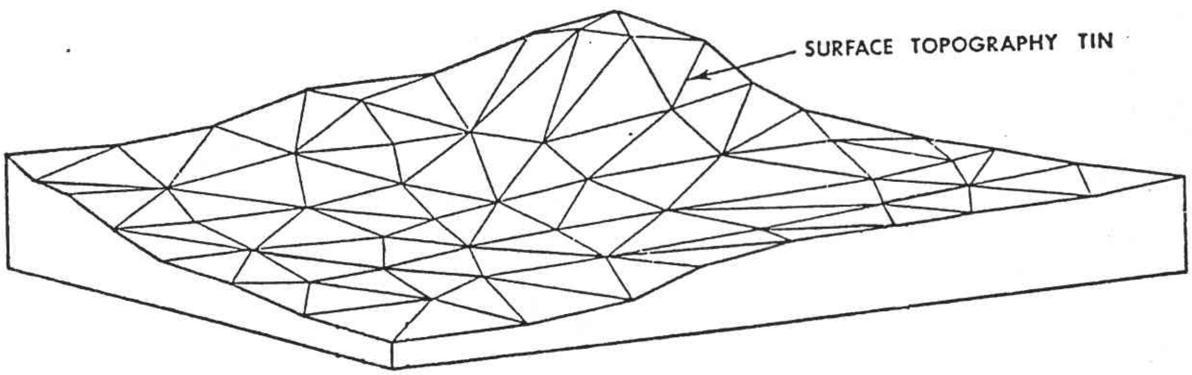
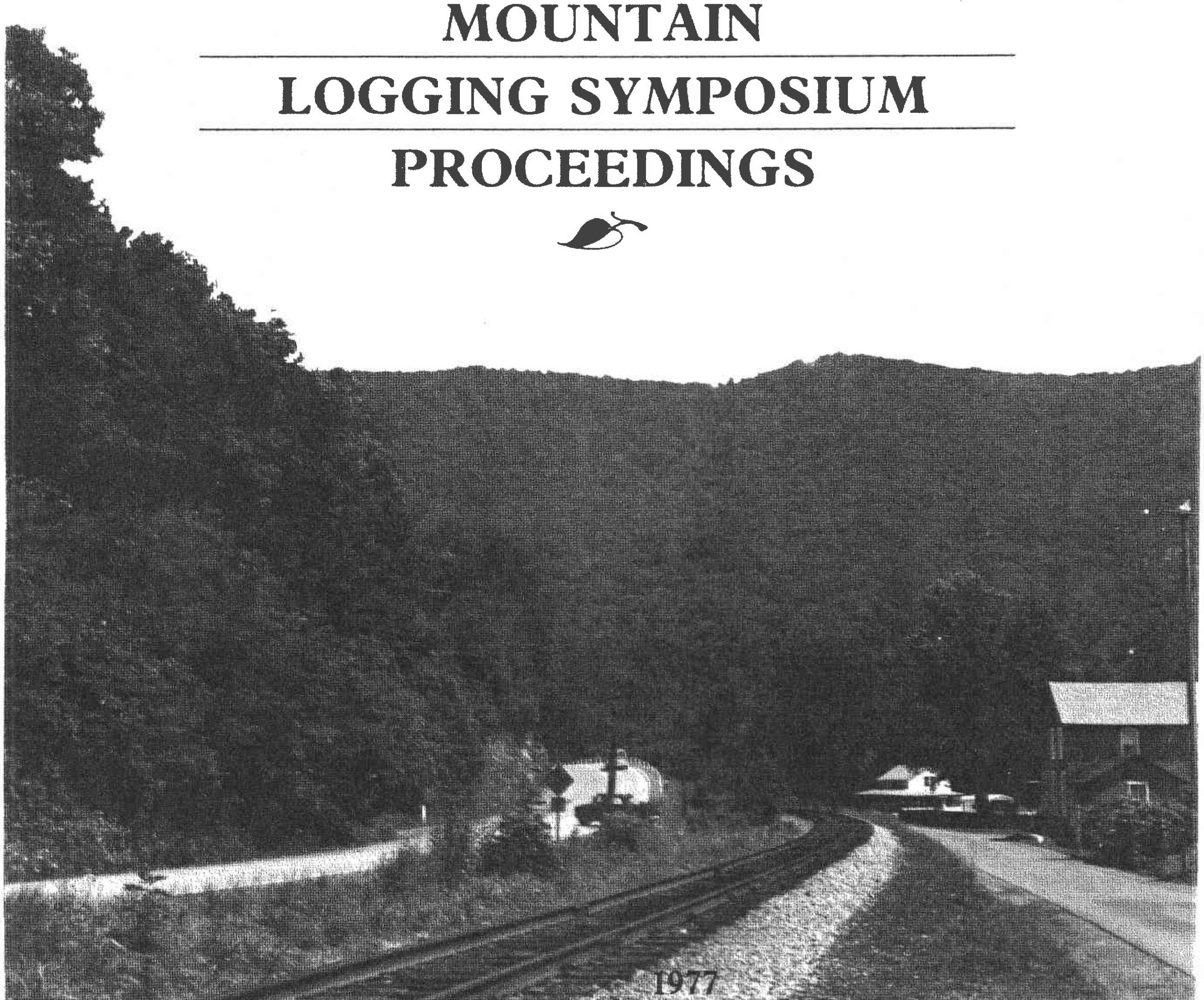


Figure 11. Perspective View of an Example TIN Topographic Data Base.

1975

MOUNTAIN LOGGING SYMPOSIUM PROCEEDINGS



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