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Engineering Field Notes

Engineering Technical Information System

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Road Program Costs: Continuing Efforts Addressing the Issue

Billy J. Reed
Chief, Engineering Management Branch
Washington Office Engineering

The Chief initiated a series of "brown bag luncheon" meetings this spring with key leaders of national organizations and groups. The purpose of these meetings was to provide an overview of the Forest Service programs included in the fiscal year 1989 President's budget request. These informal meetings provided a forum for a brief presentation by the Staff Director and a question-answer session. The person-to-person discussions helped clarify many misconceptions regarding the Forest Road Program and highlighted many of the accomplishments we have made in effectively managing the Road Program.

Dave Hessel, Director of Timber, and Sterling Wilcox, Director of Engineering, respectively, conducted the Timber and Road Program presentations on March 7, 1988. In addition to the Chief and Staff, individuals from the following organizations and groups attended: Jackson Hole Alliance; The Wilderness Society; National Wildlife Federation; National Association of Counties; National Woodland Owners Association; Preston, Thorgrimson, Ellis, & Holman; Society of American Foresters; National Forest Products Association; Wildlife Management Institute; Sport Fishing Institute; Trout Unlimited; and Sequoia Forest Industries.

One copy of each presentation was sent to the Regional Directors of Engineering. Space does not permit reprinting them in this article; however, copies of the presentations can be obtained by contacting your Regional Engineering Office or Washington Office Engineering. EFN

NSPE NEWS

National Society of Professional Engineers

1420 King Street
Alexandria, Virginia 22314
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FOR IMMEDIATE RELEASE

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ROBERT E. HARRIS, P.E., NAMED ENGINEER OF THE YEAR

ALEXANDRIA, VIRGINIA, February 12, 1988--Robert E. Harris, P.E., has been named "Engineer of the Year" of the Department of Agriculture's Forest Service. Mr. Harris, a resident of Concord, California, works for the agency at the Pleasant Hill Engineering Center. Mr. Harris is one of 33 federal agency winners nationwide competing for the title of Federal Engineer of the Year.

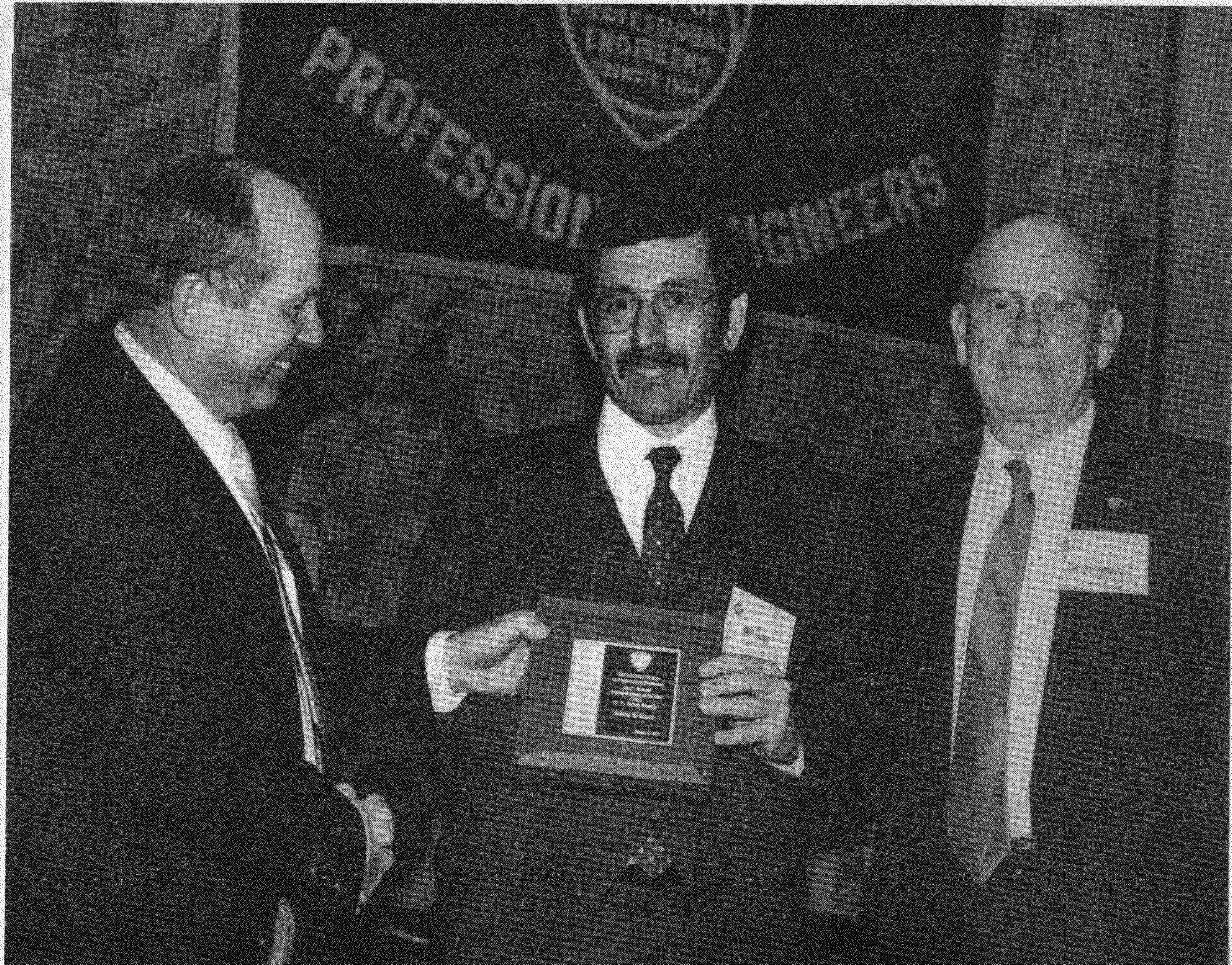
Mr. Harris will receive his agency award on February 17 at a special recognition banquet in Crystal City, Virginia, just outside Washington, D.C. The National Federal Engineer of the Year will be announced at that time.

A master of group problem solving, Harris has initiated a state program to address problems of women in engineering, spearheaded joint multi-agency cost-efficiency activities and saved the taxpayer $3 million annually by eliminating high-cost land leases.

The Federal Engineer of the Year Awards (FEYA) program is sponsored by the National Society of Professional Engineers (NSPE) and leads into National Engineers Week, February 21-27. NSPE initiated FEYA to provide recognition for engineers employed in the federal government.

Judges for this year's prestigious awards were: Congressman Roy Dyson (D-MD); Donald L. Hiatte, P.E., Past Chairman of Professional Engineers in Government, NSPE; and Louis L. Guy, Jr., P.E., an NSPE National Director and President-Elect, Virginia Society of Professional Engineers.

The National Society of Professional Engineers, headquartered in Alexandria, Virginia, represents more than 75,000 engineers in all technical branches of the profession.



Sterling Wilcox, FS Director of Engineering, presents NSPE plaque to Robert Harris, P.E. (center), distinguishing him as Forest Service "Engineer of the Year." NSPE President Charles Samson, P.E., looks on. See facing page for NSPE News Release describing Bob's accomplishments.

United States Department of Agriculture | Forest Service | WO

Reply to: 1340-1 **Date:** MAR 2 5 1988

Subject: Employee Suggestion Bulletin

To: Regional Foresters, Station Directors, Area Director, and WO Staff

In past years it has been our practice to issue an annual "Employee Suggestion Bulletin" which contained all suggestions adopted at the national level. Although this appeared to have been a useful practice, we think it is now appropriate to implement alternative methods for "marketing" employee suggestions using available technology and disseminating this information in a more timely, useful, and cost-effective way.

Although our long range plans are to establish electronic forms and develop a process for speeding up the suggestion approval process, we are taking several steps now. In lieu of issuing a Bulletin, we are enclosing a brief flyer listing those suggestions adopted at the national level this past year. We will continue doing this in the future on a quarterly basis.

The functional area, name(s) of the suggester, Washington Office and field unit suggestion number, where the suggester is located, subject of the suggestion, and information on the adoption of the suggestion are indicated for each suggestion included in the flyer. If you need additional information on any of these suggestions please contact the suggester direct.

Our second step will be to work with the Washington Office (WO), Computer Sciences and Telecommunications and Information Systems Staffs to create a public file for adopted suggestions. When this file is in place, subsequent suggestions will be placed into this file for reference purposes. After we have distributed the flyer in hard copy we will send a copy via Data General to the field Employee Suggestion Coordinators and request that they create a public file and file the flyer in it for reference purposes also.

Finally, various WO Staffs periodically issue newsletters, pamphlets, and other types of material such as Timber Tips, Engineering Notes, etc. We propose to work with these staffs and incorporate appropriate suggestions into their documents to reach their interest groups. Consideration is also being given to periodically include suggestions in the "Friday Newsletter."

Your comments regarding the proposed direction to improve publicizing adopted suggestions would be greatly appreciated. Please direct any questions you may have to Bernadine L. Jones-Gibbs, 235-9793, or Forrest Fenstermaker, 235-9794.

James E. Webb

JAMES E. WEBB
ASSOCIATE DEPUTY CHIEF

Enclosure

FS-6200-28(7-82)

Employee Suggestion Bulletin

In order to "market" employee suggestions Service-wide, as called for in Associate Deputy Chief Webb's March 25, 1988, letter (see page 4), Engineering Field Notes *will be posting suggestion-related announcements in this and future issues.*

Engineering Field Notes *will focus its announcements on those suggestions that deal with Engineering-related activities and that have been approved for Service-wide use. We agree that the wide dissemination of this information is essential for two reasons:*

(1) It will help spread an awareness at all levels of techniques that can save time and money—multiplying the eventual savings.

(2) It will provide some much deserved recognition to employees who are trying to make the Forest Service a more efficient and effective agency.

We hope to be able to provide the "Employee Suggestion Bulletin" to EFN readers at least every other issue.

—Editor, EFN

7140—Geometronics

Marty J. Christensen 6172 (R9-8631)

Location:	Chippewa National Forest Deer River Ranger District
Adopted:	Optional Service-wide

Develop new measurement technique using 35mm photography and electronic planimeter for quick response to measure acres on site preparation contracts.

7160—Signs and Posters

Galen Christensen 6139 (R2-11-86)

Location:	Medicine Bow National Forest Supervisor's Office
Adopted:	Optional Service-wide

Develop a method to control porcupine damage to signs in the National Forests.

Mark Hinschberger 6162 (R4-03-074)

Location: Bridger-Teton National Forest
Big Piney Ranger District
Adopted: Service-wide

Design poster mount, which allows the poster to slide into a wooden frame, securing the poster on all four sides.

Gordon M. Williams 6151 (R4-18-071)

Location: Uinta National Forest
Supervisor's Office
Adopted: Optional Service-wide

Provide a way to recognize volunteer conservation efforts performed by organizations and groups under adopt-a-trail and adopt-a-stream program.

Peter Martin 6204 (R6-997)

Location: Mt. Hood National Forest
Bear Springs Ranger District
Adopted: Optional Service-wide

Develop poster mount for high- and medium-speed roads to improve the poster mount and save maintenance costs in heavy snow and high-vandalism areas.

7700—Transportation System

Bob McCrea, Gary Hemstead, Parks Harris, and Larry Orcutt 6182 (R5-5413)

Location: Shasta-Trinity National Forest
Shasta-Lake Ranger District
Adopted: Service-wide use

Replace culvert pipe located in fills, by inserting polyethelene pipe into the old pipe and filling the void between the two with concrete grout.

Lester Pence and Dick Jones 6148 (R08-2986)

Location: Regional Office
Engineering Staff
Adopted: Optional Service-wide

Construct a polymer grid confinement system where a road crosses a stream. This is a good alternative to the concrete plank crossing presently used.

Thomas B. Abdo 6278 (R9-8726)

Location:	Superior National Forest Supervisor's Office
Adopted:	Service-wide

Use supporting road culverts in a swamp crossing to provide good longitudinal support at swamp crossings and reduce maintenance.

Benjamin F. White 6175 (R9-9651)

Location:	Monongahela National Forest Supervisor's Office
Adopted:	Optional Service-wide

Plan for and order aluminum corrugated pipe in exact lengths instead of even lengths as previously done. EFN

Guidelines for Basic Data Input to a Geographic Information System

Carolyn K. Holland
Cartographer
Geometronics
Washington Office Engineering

Introduction

This article is one of a series of briefing papers from the National GIS Steering Committee that addresses issues involved in the successful implementation of a geographic information system (GIS). Each Forest will eventually embark on a major data collection effort as part of its GIS implementation. To do this as efficiently as possible, it is important to carefully consider what data are needed and what level of accuracy and detail is required for those data. It is recognized that various types of data may require different accuracy standards; however, definition of those standards is beyond the scope of this article. Rather, this article focuses on factors affecting data accuracy, including scale of the source document, National Map Accuracy Standards (NMAS), cartographic generalization and simplification, line widths, feature offsets, digitizer accuracy, paper shrinkage and expansion, photo-relief displacement, the Global Positioning System (GPS) and new horizontal datum, and ground surveys. In the course of the discussion, all the major sources of data (maps, photos, terrain data, survey data, and GPS) will be covered. The consequent effects on GIS analyses are discussed.

Factors to be Considered

Factor 1

The act of representing a portion of the Earth's surface on a small piece of paper obviously involves a tremendous size reduction of every feature portrayed. The mapmaker attempts to place each feature on the map in the position most closely corresponding to the feature's location on the ground. Because a tiny distance on the map represents a large distance on the ground, there is plenty of opportunity for error in positioning. Some maps specify in the legend that they conform to NMAS, which state that at scales larger than 1:20,000, 90 percent of the points are plotted within 1/30 inch of their true location. For smaller scales (for example, 1:24,000), the requirement is 1/50 inch. Bear in mind that a scale of 1:24,000 means that one unit of measurement on the map corresponds to 24,000 of the same units of measurement on the ground (that is, 1 inch on the map equals 24,000 inches, or 2,000 feet, in the real world). Also remember that 1:24,000 is referred to as a larger scale than, say, 1:48,000 because a line 2 inches long on the 1:24,000 map will only be 1 inch long on the 1:48,000 map.

There are three map series used by the Forest Service that conform to NMAS. These are the 1:24,000, 7-1/2-minute Topographic Series, produced by the U.S. Geological Survey, and the Primary (1:24,000) and Secondary (1:126,720) Base Series, produced by the Forest Service's Geometronics Service Center (GSC). NMAS call for 90 percent of the points to be within 1/50 inch of their true location. At 1:24,000, 1/50 inch on the map corresponds to 40 feet on the ground:

$$\frac{1}{24{,}000} = \frac{1/50}{x}$$

$$x = 0.02 \times 24{,}000 = 480'' = 40'$$

This means that NMAS allow a possible error of up to 40 feet in the position of features on the map. At either the Secondary Base or Forest Service visitor map scale of 1:126,720, 1/50 inch means a possible error of as much as 211 feet. These are fairly stringent standards, and maps not generated with the standards specifically in mind are likely to be considerably less accurate.

Table 1 shows the horizontal error allowed by National Map Accuracy Standards for the map scales used most often by the Forest Service. Remember that unless the legend indicates that the map meets NMAS, the error is probably worse than shown.

NMAS also define standards for vertical accuracy (that is, terrain or elevation data). Ninety percent of the elevations must be accurate to within one-half the value of the map's contour interval. Since smaller scale maps generally have a larger contour interval, their absolute vertical accuracy is not as good. For example, 90 percent of the elevations on a map with a 20-foot contour interval must be within 10 feet of their true value; for a 100-foot interval, elevations only need to be within 50 feet.

Probably the most widely used source of terrain data is the Digital Elevation Models (DEM's) produced by the U.S. Geological Survey and the GSC. Horizontal accuracy can be no better than the source, which is either an aerial photograph or the contours on a 7-1/2-minute, 1:24,000 quad map. The data collected are then processed through a gridding routine to produce

Table 1.—Horizontal error allowed by NMAS.

Scale	*Real-distance horizontal error (feet)*	*Corresponding map error (inches)*
1:12,000	33	1/30
–	–	–
1:20,000	33	1/50
1:24,000	40	1/50
1:63,360	106	1/50
1:126,720	211	1/50
1:250,000	417	1/50
1:2,000,000	3,333	1/50

elevation values at regularly spaced locations. The standards for DEM's require the results to meet one of two vertical-accuracy classes: less than 7 meters (two-thirds of the elevations are within 7 meters, or 23 feet, of their correct value) or between 7 and 15 meters.

Factor 2

Along with the size reduction involved in representing the Earth's surface on a map are generalization and simplification. Clearly, every detail of a complex coastline or meandering river cannot be shown on a map; the paper just is not big enough. The cartographer must attempt to give an accurate rendering of the feature while eliminating much of the detail. The smaller the map scale, the less available space there is to show the same ground area and the more detail there is that must be simplified or eliminated. For example, a group of islands might be generalized to show only one or two of the biggest islands; a broad river for which both banks are depicted at a large scale is likely to be drawn with a single line at a smaller scale. Consequently, area features at a large scale may become point or line features at a smaller scale; minor features may be eliminated completely. Thus, scale and the resulting generalization can have major consequences on the digitizing process.

Factor 3

A line of measurable width represents features on a map. Depending on the map scale, the space this line takes up on the map may be more than the real-world feature takes up on the ground. For example, a common line width used on maps is 0.005 inch. This seems tiny, but at a scale of 1:24,000, it corresponds to 10 feet on the ground; at 1:126,720 (the scale of the Forest Service visitor map), it is 53 feet. The actual feature might be a trail only a few feet wide.

As a result, when features are closely spaced on the ground, correct positioning on the map is likely to put them on top of each other. Since the map would then be illegible, the cartographer is forced to shift one or more of the features away from its true position, thereby avoiding overlap. The smaller the map scale, the more likely this is to occur. The classic example is that of a road, a river, and a railroad all running through a narrow valley. Suppose the total width they take up is 100 feet. Each feature is to be drawn on the map with a line 0.005-inch wide, and a space of the same width is required between each, for a total of 0.025 inch. The smallest scale at which this is possible without shifting some of the features is 1:48,000. In practice, this sort of conflict will occur at any map scale and will result in varying degrees of error in the position of a feature.

Note that factors 4 and 5 apply to both maps and aerial photography.

Factor 4

Getting data into the GIS from a map or photograph source requires digitizing. In this phase, accuracy is affected by the hardware and the operator.

In general, digitizers are advertised by their manufacturers as having a certain accuracy. This should *not* be confused with resolution or precision. For example, the Calcomp digitizer included in the Lot-7 (HP9000) procurement has a resolution of 0.001 inch; that is, it will record numbers to three decimal places. However, its accuracy (how truly the machine is capable of representing a point's position) is only good to 0.01 inch. This corresponds to a possible error of 20 feet at 1:24,000, 105.5 feet at 1:126,720, and 67 feet at the National High Altitude Photography scale of 1:80,000.

The digitizer operator also affects accuracy. How closely the digitizer operator follows the line and whether he or she sticks to the center of it or one of the edges will affect how accurately the feature is ultimately represented in the computer. The digitizer operator also decides, consciously or not, whether to digitize every nook and cranny shown on the source or to further generalize the feature. Other judgment calls required of the operator include such situations as digitizing polygons drawn on a photograph with a fat pen: Should the inner edge, the center, or the outer edge of the line be followed? As a concrete example, consider a line 1/10 inch wide on a 1:24,000 scale photograph. That line width covers a distance of 200 feet on the ground. For the sake of simplicity, assume the polygon being digitized is a circle with radius of 1,000 feet; its area is then approximately 72 acres. If the outer edge of the boundary line is digitized, the radius grows to 1,200 feet and the area grows to 104 acres.

Factor 5

If the source document, whether a map or a photograph, is on paper, there are also the problems of shrinkage and expansion to consider. Paper is not a stable material; it can easily shrink or expand in size by 1 percent as it is creased and wrinkled and exposed to various conditions of humidity and temperature. To put this in perspective, consider the 1:24,000 map series, in which an average map sheet covers 24 inches in the north-south direction. One percent of 24 inches is almost 1/4 inch—a ground distance of 480 feet.

Factor 6

Factors affecting accuracy are inherent to every data source. For photographs, in addition to the problems previously listed, various distortions can be introduced by the lens, the Earth's curvature, and atmospheric refraction. Another quirk of photographs is that, with the exception of orthophotographs, the photograph scale varies with terrain. Given a photograph taken from a flying height of 40,000 feet above datum, with a camera focal length of 6 inches (0.5 foot), the photograph scale for all points at datum is:

$$\frac{0.5}{40{,}000} \text{ or } 1{:}80{,}000$$

However, at a point 1,000 feet above datum, the scale is 0.5:39,000, or 1:78,000. These variations in scale will affect the accuracy of any measurements taken or coordinates digitized. Relief displacement, wherein an image's position shifts with its elevation, is another factor. In uneven terrain, this can cause a straight-line feature to look crooked; the digitized version also will be crooked.

As far as survey data are concerned, Forest Service cadastral surveys must meet an error requirement of no worse than 1 part in 5,000. The error requirement for Engineering surveys ranges from 1 in 1,500 down to 1 in 30. Thus, given a 5-mile road and assuming the first point is correct, the positional error of the final point could range from 18 feet to 880 feet, depending on the level of Engineering survey used.

Before discussing the remaining major source of data, we must first explain the coordinate systems used when collecting data. To pinpoint a position, a coordinate system must be defined. This includes an origin, from which measurements will be made, and units to be used for those measurements. For the spherical Earth, measurements can be made by subdividing its circumference into 360 degrees. This is done with the geographic coordinate system, or latitude-longitude, in which measurements are made along north-south (latitude) and east-west (longitude) circumferences to define a particular point's location. However, a system based on circles and spheres is impractical for measurements when the Earth is represented on a flat piece of paper. Various planar coordinate systems, most commonly state plane and Universal Transverse Mercator (UTM), have been devised to fill this gap. All these systems attempt to approximate the impossible (imagine trying to cut open a hollow ball in such a way as to turn it into a flat, *undistorted* rectangle) while minimizing the inevitable distortion. This is achieved by dividing up the Earth's surface into sections within which distortion will have little effect on measurements (that is, you can come closer to turning that hollow ball into several dozen small, flat rectangles rather than one large, flat rectangle) and defining a new coordinate system origin in each section. The state plane and UTM coordinate systems do exactly that.

The situation is further complicated because the Earth is not a perfect sphere. Various reference spheroids are therefore defined that approximate as closely as possible a given area of the Earth's surface. For the United States, this has resulted in something called the North American Datum of 1927 (NAD27). All maps and surveys made since that year, and the coordinate systems used, are relative to NAD27; however, a newer, more accurate datum (NAD83) has been defined, and coordinate systems have all been shifted accordingly.

This brings us to the last data source to be discussed, the GPS, which consists of a group of satellites that are tracked by a movable, ground-based receiver to compute the receiver's position. Depending on whether one or two receivers are used and whether both are stationary when readings are taken, the resulting coordinates are accurate to within 2 to 25 meters (7 to 82 feet). The drawback is that all GPS coordinates are based on the new horizontal datum (NAD83). Because all other data sources are based on NAD27, the GPS coordinates must be converted to that datum if they are to be merged with those data sets. In many cases, the state plane coordinate system has been redefined for NAD83, so that coordinate values for the same point on the two datums are not even in the same ballpark. Although the situation is not as extreme for the UTM coordinate system, the datum shift can still amount to several hundred meters.

Effects & Conclusions

It is obvious from the preceding discussion that scale is one of the major factors affecting data accuracy. However, once the data are digitized and entered into the computer, all reference to scale is lost. The digitizer collects an X-Y coordinate pair for each point; once in the GIS, all data from all sources must be in a common ground-based coordinate system (for example, state plane or UTM). The system has no knowledge of how accurate any given coordinate pair is relative to its true ground location or even relative to another coordinate pair supposedly representing the same ground location. In practice, the same ground location digitized from two different sources is likely to yield very different X-Y coordinates.

For example, suppose you have a timber stand bounded on one side by a road. The road was digitized from a 1:24,000 Primary Base map, meeting the NMAS. The timber stand was digitized from a polygon outlined on a photograph. The chances of the polygon border matching the road when the two are overlaid are slim to nonexistent, because of all the factors outlined in the earlier discussion. How do you decide which version is more correct? Which system would you rather use to calculate acreage for that timber type?

In a GIS, data will be merged from many sources and scales, and each source will have unknown amounts of error and generalization built in. As a practical example, a river digitized from a 1:24,000 map and again from a 1:126,720 map and then overlaid at a common scale may show no common points at all between the two digitized versions of the same feature. In addition, one version will be far more detailed in its shape than the other. Each was portrayed and digitized as accurately as possible *at its source map scale*, but because of the effects of scale on generalization, simplification, and feature offsetting, overall space and size limitations, and factors in the digitizing process, the results are simply not the same. Similarly, given a feature extending across map boundaries and thus digitized from two different source documents, there are almost certainly edge-matching problems when it is time to link the two pieces.

Before going any further, it must be emphatically stated that photographic enlargement of all source material to a common, large scale is *not* the solution. Accuracy will not improve, nor will additional information be acquired; all you will have is a big piece of paper instead of a little one.

Users who get themselves into this situation with their data will need sophisticated, interactive editing software and massive amounts of time to resolve problems. When two lines that should match do not, do you choose some point in between the two? Do you backtrack to the source and collection method to decide which is more accurate? Once you have made that decision, what contortions will your GIS put you through to make a correction that affects multiple layers?

Many of these problems can be eliminated or at least minimized by recognizing them in advance and approaching the data-collection phase accordingly. The GSC is responsible for digitizing all layers used in producing the 1:24,000 Primary Base Series maps: hydrology, transportation, boundary, topography (DEM), landnet, land status, and culture. Further information on the composition of these layers is contained in the document "Digital Data Standards for Base Series Mapping Layers" (refer to Hartgraves' 1390/7140 letter of April 27, 1987). These data meet NMAS and are collected from a relatively large-scale source, the largest scale at which a substantial and growing amount of data of known accuracy standards are available. They incorporate less error because of generalization and feature shifting than would data collected from a smaller scale map. Data collection is from stable-base mylar (very little shrinkage or expansion); the data are checked for accuracy and edited as needed; and each quad is edge-matched to adjacent quads.

These layers give the Forest a good start on meeting GIS input-data needs. Because they provide a guaranteed accuracy and level of detail across the entire Forest, additional layers can be tied to them. Data collection from source documents at either 1:24,000 scale or as near to that as possible is recommended for the additional layers the Forest will need. This will minimize data inconsistencies that result from using very different scales and accuracy levels. Where problems are found, chances are that the data from the Base Series layers are the most accurate and should be given preference.

In any case, users should bear in mind that GIS output can be no more accurate than the *least* accurate input and in fact will incorporate some error from all the input sources. Users should carefully consider the error that will be introduced before choosing a source for digitizing data. The ultimate goal is to provide data of sufficient accuracy and detail for the planned analyses without wasting resources collecting unnecessary data.

Reverse Photogrammetry: A Better Method of Locating Lines in the Field

Wayne Valentine
GIS Coordinator
Region 1

Introduction

Resource managers, foresters, engineers, surveyors, loggers, and many others often have the job of establishing the location of lines on the ground. Lines are needed for a vast variety of purposes, including defining wilderness or other boundaries, establishing locations of proposed new roads, flagging the limits of clearcuts, marking the locations of cable settings or proposed range fences, and delineating allotments. Often the location of a line is defined in the field during field work. The line so located must then be plotted on a map; however, many times the line is first located on a map and must then be placed on the ground in the same location as its theoretical map position. The latter is often a problem to perform correctly. Reverse photogrammetry can help.

When a map line follows a natural feature (for example, a stream or ridge), placing it on the ground is usually not difficult. However, when the line is "imaginary" (that is, initially drawn on the map as a theoretical or planned location without reference to an existing feature), locating it in the field to an acceptable level of accuracy is often not only difficult, but also time consuming and expensive.

One means of accurately locating such imaginary lines is by surveying—using such distance- and angle-measuring instruments as a tape and a compass or transit. The person making the location starts from a known point and then lays off calculated angles and distances. This process is not only costly and time consuming, but it is also prone to mistakes. Moreover, an entire section of a line must be surveyed to "anchor" it between known points, even if only a small segment in the middle of the line is actually needed. This requirement adds to the cost of locating lines by survey.

The only other practical way of locating a line is by inspecting—using a visual reference to a map of the area. This method seldom results in an accurate correspondence between the mapped or theoretical location and the location marked on the ground because of lack of detail on the map, small map scale, and limitations in map-reading skills.

Photographs also can be used for locating lines by inspection. To use photographs, first transfer the imaginary line from the map to the photograph. In the past, this step has been difficult to routinely perform for precision work because of several technical problems.

Advantages of Photographs

Field-going personnel have long recognized the advantages of using aerial photographs to inspect ground conditions. The aerial photograph is unsurpassed in its detail. Aerial photographs have been used for years to delineate ground conditions that will later be transferred to a map. This transferral is necessary because the map has a uniform scale while the photograph does not, making it impossible to accurately determine acreage or measure distances and direction from the aerial photograph without special equipment.

To deal with the scale variables of the aerial photograph, the science of photogrammetry was developed. Photogrammetry allows accurate transfer of information from a photograph to a map and is used almost exclusively in modern mapmaking. Photogrammetry requires special instruments and skills and is an office, not a field, operation. Heretofore, photogrammetry has not been extensively used for the precise transfer of information from a map to a photograph because of equipment limitations and control difficulties; however, these problems now have been overcome by reverse photogrammetry.

Reverse Photogrammetry

Reverse photogrammetry uses analytical systems that enable one to plot imaginary lines directly onto photographs in the actual perspective of the photograph. An imaginary line representing a proposed feature can be plotted in exactly the same position as the image of the actual feature, as if it existed. For example, an imaginary line representing a proposed powerline can be plotted in the location and at the height that the powerline is planned to occupy. Subsequent viewing on a stereo pair will verify this.

If the photograph is large enough, these imaginary lines can be fairly accurately placed on the ground simply by visually examining and ground-replicating the relationship between the imaginary line and the images of features on the photograph. Imagine the implications of this capability for the layout problem. The cost of locating lines can be reduced, if for no other reason, by only having to locate separately those line segments that are actually needed.

What does it take to make reverse photogrammetry work? Solving the photogrammetry problem by analytic photogrammetry requires that the space location and orientation of the photographs' stereo pairs be computed. If the ground coordinates and elevation of points on the imaginary line are likewise known, one can use a fairly complex mathematical solution to compute the position of the imaginary line in the photograph's coordinate system for plotting on the photograph. This solution requires that the geometry (the X, Y, and Z coordinates) of the line to be plotted be known. If the geometry is unknown, it easily can be determined by map digitizing the X and Y coordinates and using analytical photogrammetric methods to measure the Z coordinate.

Two Other Major Advantages of Reverse Photogrammetry

True Scale

While both the ground and photograph coordinates of points on an imaginary line will have been determined for reverse photogrammetry, one other set of very useful numbers can be calculated—the true photograph scale between pairs of points. Knowing the exact photograph scale will permit direct measurements to be taken from the photograph in the vicinity of these pairs of points. These measurements can be taken in the field using hand-measuring tools. If the photograph is of sufficiently large scale, it will be a more useful tool for field layout. The line need no longer be laid out solely by inspection; it also can be located by measurements from objects shown on the photograph where true distance to the line has been scaled directly on the photograph.

Large Scale

Of course, the photograph must be large enough to permit field measurements of meaningful discrimination when using hand equipment. The usual resource scale ranges from 1:12,000 to 1:24,000. But even the "large," 1:12,000 (1,000 feet per inch) scale may be too small for fine-enough measurements. The solution to this problem is to have the photograph enlarged in the vicinity of the line to be located. Modern aerial cameras and films produce photographs of superb resolution, capable of being enlarged perhaps up to 10 times without a crippling loss of image quality. Thus, even the "small" resource scale of 1:24,000 can be enlarged to 200 feet per inch. This scale will permit field measurements that are relatively accurate (approximately ±2 feet, by measuring to 0.01 inch on the photograph). These measurements are good enough to locate most lines with which the Forest Service is concerned. Of course, larger scale, original photographs will permit even greater accuracy.

The imaginary line must be plotted on the photograph after enlargement, not before. Otherwise the line itself would be enlarged, reducing its usefulness. How can this be accomplished? Before plotting on the photograph, the photograph coordinate system must be established. This is done by reference to the photograph fiducial marks. Only a portion of the photograph may be enlarged (because of size limitations), so the fiducial marks will be lost. However, substitute images whose photo coordinates have been measured in advance can replace these lost marks.

The Cabinet Mountain Wilderness Boundary

The Cabinet Mountain Wilderness lies atop the Cabinet Mountains in the Kootenai National Forest in northwestern Montana. These mountains are heavily mineralized with silver-, copper-, and gold-bearing ores. Mineral exploration has been extensive in the areas adjacent to the wilderness, and recently, a new mining operation was begun.

When the wilderness was established decades ago, its boundary was poorly defined. The official map used is small scale, and the defining line was placed, in many critical areas, without reference to such natural features as ridges and streams. Also, as is the case with many wilderness areas, the official description is poorly worded and vague. This required intensive study of the map, description, and congressional records to discover the intent of the boundary scriveners.

To make a reasonably precise interpretation of the boundary location, cadastral surveyors of the Kootenai had to resort to digitizing the boundary as shown on the original map and then reducing the line to a series of bearings and distances between points defined in the Montana State Plane Coordinate (SPC) System. It was expected that this line would have to be surveyed by the traditional method of traversing from known points that mineral surveyors had established, monumented, and tied into the Montana SPC System in connection with survey work needed to establish mining claims. It was important for both wilderness and forest management purposes to establish portions of the boundary in areas near the claims—to protect the wilderness and, at the same time, to allow mineral extraction to the full extent of the claims.

The area is extremely rugged, with a short field season because of the altitude of this mountainous environment. Surveyors face the tough job of locating, marking, and posting the wilderness boundary in a short timeframe.

Meanwhile, Geometronics Staff in the Regional Office had been working on reverse photogrammetry. Concepts and procedures needed a test. Would reverse photogrammetry work in the real world? The Cabinet Mountain Wilderness boundary problem provided a great opportunity to answer that question.

Existing resource photography at a scale of 1:12,000 of the area was pulled from files. High-altitude photography, bridged and pugged by the U.S. Geological Survey, was also used in two-scale, aerotriangulation to control the resource models. A data file of the digitized boundary line was loaded into Region 1's Wild BC-1 analytical plotter and used to drive a profiling program. The boundary was then profiled in the BC-1 from the resource models, adding the Z coordinate (elevation) to the X and Y ground coordinates of points on the boundary.

Appropriate single photographs of the area were enlarged four times and digitally registered onto the Region's Wild TA-10 plotting table. The BC-1 data file of three-axis ground coordinates, the camera calibration, and exposure station information were processed through Region 1 Chief of Photogrammetry Bob Boller's program, PROFIT, which incorporates former Region 5 Photogrammetric Engineer Gerry Salzig's subroutine COLINE to compute the colinearity equations and transformation parameters. PROFIT transformed the ground data into two-axis photo coordinates for plotting on the enlarged print. The actual photograph scale between points was computed. Note the large change in scale along the line (see table 1, right column). Ground distances and bearings between points on the line were also computed (see table 2).

Table 1.—Ground coordinates in feet and image coordinates in millimeters.

			Ground			Image		Photo
Plate	Code	Point	XP	YP	ZP	X	Y	Scale
332	306	99	496881.543	442831.205	4745.711	693.967	940.217	1: 0.
332	307	100	496812.433	442808.911	4708.105	695.239	933.998	1:3487.
332	308	101	496697.525	442770.310	4638.398	697.316	923.481	1:3447.
332	309	102	496639.597	442740.732	4588.941	698.804	917.742	1:3344.
332	310	103	496620.273	442765.352	4531.797	696.169	914.184	1:2154.
332	311	104	496573.149	442759.011	4546.301	697.114	911.481	1:5061.
332	312	105	496529.251	442766.330	4556.129	697.009	908.761	1:4983.
332	313	106	496153.822	442749.109	4605.508	699.494	905.386	1:5626.
332	314	107	496388.875	442745.416	4647.711	700.863	902.392	1:6024.
332	315	108	496284.567	442752.376	4719.004	702.236	897.601	1:6393.
332	316	109	496153.852	442760.646	4815.617	704.149	891.773	1:6508.
332	317	110	496045.053	442782.333	4889.484	704.580	886.543	1:6442.

Input is ground X-Y-Z with no transformation.

Table 2.—Coordinates, bearings, and distances.

ID	X	Y	Bearings	Distance	AZM(N)
99	496881.54	442831.20 PT 98 TO 99	S69 1 10W	91.117	249.02
100	496812.43	442808.91 PT 99 TO 100	S72 7 16W	72.617	252.12
101	496697.52	442770.31 PT 100 TO 101	S71 25 53W	121.219	251.43
102	496639.60	442740.73 PT 101 TO 102	S62 57 4W	65.042	242.95
103	496620.27	442765.35 PT 102 TO 103	N38 7 43W	31.297	321.87
104	496573.15	442759.01 PT 103 TO 104	S82 20 11W	47.548	262.34
105	496529.25	442766.33 PT 104 TO 105	N80 32 4W	44.505	279.47
106	496453.82	442749.11 PT 105 TO 106	S77 8 21W	77.369	257.14
107	496388.88	442745.42 PT 106 TO 107	S86 44 44W	65.052	266.75
108	496284.57	442752.38 PT 107 TO 108	N86 10 58W	104.540	273.82
109	496153.85	442760.65 PT 108 TO 109	N86 22 48W	130.977	273.62
110	496045.05	442782.33 PT 109 TO 110	N78 43 37W	110.939	281.27

Note: Coordinates, bearings, and distances are based on state plane zone number.

For a portion of this project, offsets to the line from adjacent imagery were measured in the stereo plotter to an accuracy of less than 2 feet—good enough for this situation. Because the imaginary boundary line now shows on a very large air photograph with areas of precisely known scales, other portions of the line can be located in the field, as needed, by using direct measurements from imagery adjacent to the line. One can expect accuracy between 3 to 6 feet using field equipment. In this case, reverse photogrammetry was used to save time and money and to actually improve accuracy over location-by-inspection methods.

Conclusion

Reverse photogrammetry is increasingly being used for many applications in Region 1. In addition to the wilderness boundary example described in this article, reverse photogrammetry has been used to locate boundaries of mining claims, to portray the Forest boundary for court exhibits in trespass cases, to locate photogrammetrically measured profiles for cable-logging systems, and to show road center lines and photogrammetrically derived cross-section locations and limits for road construction and reconstruction projects.

We expect reverse photogrammetry to have many future applications, especially for wilderness and other boundary problems where lines go cross-country without reference to natural features. Other applications include testing line-of-sight or intervisibility, defining the intersection of subsurface layers with terrain, and plotting above-surface features, as well as surface lines. Reverse photogrammetry will allow accurate location of imaginary lines in the field using simple tools such as a tube magnifier and cloth tape. Reverse photogrammetry can help to avoid expensive field surveying and allow an economic layout of only those line segments that are actually needed. EFN

Radon Gas—An Invisible Safety Hazard

WO-E Remarks

Because radon is often very localized, you should consult your local area authorities or unit facilities or environmental staff before testing your home for radon. The Forest Service has a radon survey program that is being implemented throughout the organization for all offices and Service-owned facilities.

Environmental Protection Agency-approved test kits are available through commercial sources and cost anywhere from about $10 to $50. The test is very simple; you expose the small test kit in the lower portion of your home for several days and return it to the specified lab and wait for the results to be mailed to you.

When it comes to safety, people tend to ignore those things that they cannot see. It is the old adage, "out of sight, out of mind." Sometimes this means that we avoid seeing safety problems, or if we "accidentally" do see some problem, we quickly put it out of our minds and forget that we are somehow involved.

Sometimes, however, there are safety problems that we never can "see," no matter how hard we look. Some things simply escape our attention even if we are dedicated in our efforts to search them out. In such cases, the problem is that we are not "looking" in the correct way.

Radon is one of these "invisible" hazards that has the potential to harm us. It is one of the handful of environmental hazards of which we need to be aware so we may take measures to correct the problem and improve our safety.

Radon is a radioactive gas that occurs in nature. It is invisible; you cannot see it, smell it, or taste it. It is released when uranium decays or breaks down, and it is associated with granite, shale, phosphate, pitchblend, and soils derived from uranium-bearing deposits.

Outside, radon is quickly diluted, and there is rarely a reason to worry about concentrations. However, when radon seeps from the earth or from building stones, it concentrates in closed areas, such as homes and offices. These concentrations can be a significant health hazard.

What does this mean to you and your family? It means that the place where you work and live may be hazardous to your health. At this time, the only known health effect is that you have an increased risk of developing lung cancer if you are exposed to unsafe levels of radon gas.

The purpose of this safety note simply is to alert you to a situation that may affect you and your family. Now that you know that there is a potential hazard, you should treat it like any other safety hazard. First, determine whether the hazard does in fact exist in your office building or in your home. Second, take corrective action to eliminate or reduce the hazard. Finally, make a periodic followup to ensure the hazard does not recur.

There are relatively simple ways to determine whether you are exposed to a radon hazard. Radon detectors are placed in buildings for a certain time period. These are sent to special laboratories where the level of radon gas within the sampled building or area is determined. Some State and local governments have given radon detectors to homeowners in especially high-risk areas. Radon detectors are also available from privately operated laboratories that charge a reasonable fee for the test.

Your unit safety officer can obtain more information about the hazard of radon in your area. If you are concerned about radon in your home, call the nearest office of the Environmental Protection Agency. Ask for literature that describes the radon problem and explains what you can do about it.

Now that you are aware of a potential safety hazard, the next step is yours. You may choose to put it "out of sight, out of mind." Or you can find out whether you or your children are being exposed to radon gas. We encourage you to take action now. Find out whether your office is safe. Find out whether your home is safe. If either is not safe, take action to correct the problem. After all is said and done, the life you save may be your own, or the lives of your family members.

The preceding safety message was submitted by the Nationwide Forestry Applications Program. EFN

Evaluation of Turnkey Contracting

Hal Peterson
Civil Engineer
Grand Mesa, Uncompahgre, and Gunnison National Forests, Region 2

Preface

This article provides an excellent description of a Forest's experience with turnkey construction. The conclusions and recommendations appear valid for these experiences; however, readers are cautioned against overgeneralizing the findings. As more contractors develop experience and expertise with this type of contract, it is expected that costs will decrease over time. As indicated in this article, turnkey construction is generally the option of choice in the private sector. The advantages of turnkey contracting are well described. Developing a competent bidders' pool for turnkey contracting will provide a valuable alternative for accomplishing a portion of our future construction program.

—John R. Holt
Chief Construction Engineer
Washington Office Engineering

Introduction

In recent years, the trend has been to reduce the size of our work force and to contract out more of our engineering work. Turnkey contracting has received increasing interest as a means of efficiently coping with a fluctuating project workload and a smaller work force.

The process, successfully used by the private industry for several years, is relatively new to the Forest Service. Turnkey contracting involves awarding one contract that includes all (or the majority) of the engineering services and the construction work. Using one contract package, turnkey contracting essentially can take a project from the conceptual stage to the completed end product.

The turnkey contract is attractive because it increases privatization by contracting out more engineering work; allows more work to be accomplished with smaller staffs, thereby decreasing overhead costs; and allows flexibility to adjust to fluctuations in project workloads.

Is turnkey contracting the panacea we have been searching for? Is it the way of the future? Is it suited for all applications? Is it cost-effective?

Two recent road projects on the Grand Mesa and Uncompahgre National Forests provided valuable insight into these questions.

Background

Heavy precipitation and rapid snowmelt in Colorado between 1983 and 1984 created Statewide flooding and damaged many forest roads. Much of the repair work qualified for emergency relief funds administered by the Federal Highway Administration (FHWA) under the Emergency Relief Federally Owned (ERFO) Program. The ERFO Program requires that the funds be committed to construction of permanent repairs within 2 years after the disaster.

Owl Creek Road and Buzzard Divide Road were damaged to such a great extent that relocation was required. The time necessary for geotechnical investigation, route reconnaissance, and environmental-assessment preparation pushed the Forest Service to the time limit for committing the ERFO funds to construction. The Forest Service opted for turnkey contracts as a means for meeting the FHWA contracting deadlines.

The Owl Creek project consisted of 6.4 miles of relocation. It was successfully awarded as a turnkey contract in September 1986. The project included the survey, design, construction, and construction quality control.

Onsite information was limited to a flagline. The contract package included the geologist's reports, design criteria, standard detail drawings, and construction specifications. The contract was awarded for $655,384. The turnkey specifications were modeled after the Buffalo Pass turnkey project (see the March-April 1987 issue of *Engineering Field Notes*).

The Owl Creek project was different because all of the engineering services were included with construction in one contract. This project provided an opportunity to expand on the observations reported in the Buffalo Pass project.

The Buzzard Divide project consisted of 6.7 miles of relocation. The Forest Service surveyed the relocation route with a force-account crew and advertised a turnkey contract for its design, construction, and construction quality control. The low bid on this contract was rejected as it was 23 percent above the Engineer's estimate. The FHWA granted a time extension on this project to allow the Forest Service to design in-house and advertise a standard construction contract. This was a routine construction contract with an approved set of complete construction drawings, standard Forest Service construction specifications, and individual bid items for each item of work required, with estimated quantities based on the design.

The Buzzard Divide project provided an excellent opportunity to compare the costs of turnkey contracting to a standard Forest Service design construction contract.

Observations

The Owl Creek project achieved excellent end results. The project was completed and opened to the public earlier than could have been otherwise possible. Impacts on Forest Service personnel were lessened, freeing up time for other work. Combining survey, design, and construction into one contract reduced contract administration costs.

Turnkey contracting may be the most time-efficient means of completing a project. A private contractor can gear up a work force quicker than the Government and potentially design concurrently with construction. On the Owl Creek project, the contractor was able to survey, design, slope stake, and begin construction on a segment of road within 30 calendar days after the contract was awarded.

Slope-stability problems added to the complexity and risk of the Owl Creek project and may have contributed to the wide range in the bids—the high bid was 63 percent above the low bid.

The Owl Creek contract consisted of three lump-sum bid items: survey, design, and construction. Modifications to the approved design had to be negotiated because there were no contract unit-bid costs for individual work items.

Experience with the Owl Creek and Buzzard Divide turnkey contracts has indicated that some bonding companies are reluctant to bond because of the design portion of the contract. Competition on the Buzzard Divide project was greater for the standard construction contract (eight bidders) than for the turnkey contract (two bidders).

Engineering services in the Owl Creek contract were more costly than had the same services been performed by the Forest Service. This is primarily because of profit and risk costs and high-liability insurance costs. The Forest Service cost for the engineering services performed under the turnkey contract is estimated at $77,000, 37 percent less than the turnkey amount of $122,600. (This estimate is based on contracting out the survey and quality-control work and designing in-house.)

The design engineer on the Owl Creek project tended to design conservatively. Because the engineer made a lump-sum bid to the prime contractor for engineering services, the engineer's incentive to minimize construction costs was moderate. The engineer's primary interest was to reduce his costs by expeditiously selling his design to the Forest Service. A contractor with his or her own engineering staff would probably be more willing to fine-tune the design or investigate alternate designs to minimize construction costs.

There are built-in factors in the turnkey contract that may increase the likelihood of claims:

(1) The Forest Service's on-the-job presence is reduced since engineering and inspection services are contracted out.

(2) There is a potential for conflict of interest between contractor and inspector since the inspector is being paid by the contractor (either as a subcontractor or directly on the contractor's payroll).

(3) The contractor does not know how appropriate his or her bid for construction was until the design is completed and accepted by the Forest Service.

(4) Turnkey contracting opens new ground for contract interpretation. Interpretations may be inconsistent among different Contracting Officers and Contracting Officer Representatives.

(5) The prime contractor is at risk if the design has errors in it, as he or she is ultimately responsible for the design. On the Owl Creek project, the design engineer underestimated the excavation quantity by 2,500 cubic yards. The expense of this design error was absorbed by the prime contractor.

There is potential for overall cost savings, as the contractor is motivated to minimize construction costs with an economical design. Realistically, the contractor's success is determined by the competence of the design engineer, the flexibility of the turnkey specifications, and the Government's contract administration.

Progress payment determination can be difficult when there are no unit costs. Determining a price adjustment for out-of-specification materials accepted by the Government is difficult without a pay item to serve as a basis for price adjustment.

The up-front cost of bidding on a turnkey project is higher than a standard construction contract. This may eliminate some interested bidders and thus reduce competition. For the Owl Creek project, the contractor paid the design engineer $3,000 to develop estimated quantities on which to base his bid. The contractor must trust the design engineer to provide accurate estimated quantities. A low estimate on the quantities will cut into the contractor's profit margin; a high estimate will reduce the contractor's competitiveness.

Cost Comparison

Forest Service expenses were accurately accounted for throughout the life of the Buzzard Divide project. These records provided a good comparison of the turnkey contracting method with the standard construction contract with Forest Service design.

The Buzzard Divide turnkey contract package was assembled to provide as much design information as possible to prospective bidders. The package included the P-Line survey data and a soil and situation review stating station-by-station design information on cut-fill slope ratios and design recommendations. Minimum gravel depths were specified, and typical sections and standard detail drawings were included. Slash-disposal requirements, embankment-placement methods, compaction requirements, and seed mix were specified in the contract package. The Forest Service Specifications for Construction of Roads were referenced in the contract. Because there were no design quantities, the bid comprised four lump-sum bid items: design, construction staking, construction, and quality control.

Table 1 compares the Buzzard Divide turnkey contract bid prices to the actual costs incurred using a standard construction contract with Forest Service design. Table 1 validates the "gut" feeling that turnkey contracting is the more costly way of doing business. The comparison gives an idea of the magnitude of savings—in this case, the Government saved $137,663.

Because Contractor "A" and Contractor "B" bid on both the turnkey contract and the standard construction contract, we can compare their bids. This comparison is easily made by subtracting the design bid item from the turnkey contract cost, as this is the only difference in the work required by the two contracts. Bearing that in mind, the standard construction contract was less costly than the turnkey contract—by $95,930 for Contractor "A" and by $112,556 for Contractor "B." (Contractors "A and "B" ranked fourth and sixth, respectively, in the bidding for the standard construction contract.)

Conclusions & Recommendations

Turnkey contracting is attractive because it allows more work to be accomplished with a smaller staff and in a more time-efficient manner. However, the risk assumed by the contractor for an undesigned project, coupled with expensive engineering services, drives up the price for the turnkey contract. Turnkey contracting is not necessarily a cost-effective means of reducing Forest Service overhead costs, as demonstrated by these two projects.

The construction portion of a project is the largest cost center. For the economy of a project, a clearly defined construction contract (that is, a standard construction contract) will lower the contractor's risk, increase competitiveness, and result in lower project costs. Assuming a limited work force, time permitting, an architectural and engineering survey-design contract with a standard construction contract is recommended over turnkey contracting. However, the Government will realize the greatest savings if as much of the engineering services as possible are done in-house.

Table 1.—Buzzard Divide turnkey contract bid prices versus actual standard construction contract costs (dollars).

	Turnkey contract			*Standard construction contract using Forest Service design*
Item	*Contractor "A"*	*Contractor "B"*	*Engineer's estimate*	*Actual costs*
Design	45,000	53,844	42,250	22,522 (Forest Service cost)
Construction staking	20,000	29,120	11,050	28,100 (contract)
Construction	551,766	610,060	457,030	463,981 (contract)
Quality control	45,000	40,208	26,430	9,500 (contract)
Totals*	661,766	733,232	536,760	524,103

*Forest Service construction engineering (CE) costs are not included. Forest Service CE costs would be higher for the turnkey contract because of additional contract administration costs during the design phase of the turnkey contract. It is estimated that an additional $7,164 was saved on Forest Service CE costs that normally would have been spent on the turnkey design process, reflecting the cost of contract administration costs for the Owl Creek turnkey project, a job of similar size and complexity. Forest Service CE costs for the construction phase of the turnkey contract would have been essentially equivalent to the standard construction contract CE costs.

For budgeting purposes, one should anticipate a turnkey contract to cost 15 to 25 percent more than an in-house design with a standard construction contract. (For the Buzzard Divide Project, the cost for the turnkey contract was 26 percent more.)

Turnkey contracting can be a valuable contracting tool. Once the decision is made to use this contracting method, the following recommendations should be considered:

(1) Obtain adequate competition. Consider advertising longer for complex projects. Do not limit advertising to small businesses. Many big business contractors employ a full-time engineering staff, which could potentially result in lower bid prices.

(2) To reduce bid costs and encourage fair competition, include in the turnkey contract as much information as possible regarding what the Government will expect and accept. Be explicit; specify all special structures, materials, and placement methods. Do not include "nice to haves" in the specifications. Provide soils data if special designs are anticipated.

(3) Provide quality Forest Service contract administration. This is very important, perhaps more so with a turnkey contract, because of the potential for claims and the need to keep the contractor on the right track during the design phase.

(4) Perform complete and periodic design reviews, including the plan-in-hand review. They are critical to the success of the project. Ensure that a complete and detailed set of construction drawings is developed. After the Forest Service accepts the design drawings, changes to the drawings can become costly contract modifications.

Summary

Turnkey contracting can be an excellent means of accomplishing a project, especially when time is of the essence and increased funding is available. Alternate combinations of contracting and using Government personnel can be more cost-effective. Selecting the turnkey contracting method should be a management decision that carefully weighs the benefits of turnkey contracting with the higher costs and analyzes the available work force and the importance of meeting deadlines.

Field Design, Data Collection, & Plotting With the HP-41cx

Mike Dixon
Civil Engineer
Payette National Forest, Region 4

Introduction

The HP-41cx handheld calculator has been programmed to design low-standard roads in the field while collecting data used to produce plan and profile plots. The HP-41cx and the HP 7470A (option 3) plotter perform the plotting. The system is capable of designing and staking 1,600 feet to more than 3,000 feet of road per day, complete with design quantities for excavation and clearing. The plan and profile plot for a day's work can be completed in less than 1 hour after returning to the office.

Field Experience

The HP-41cx field-design system was used during the 1987 field season to design more than 12 miles of low-standard roads on the Payette, Stanislaus, and Deschutes National Forests in Regions 4, 5, and 6, respectively.

On the Payette National Forest, management decided to add 3,500 feet of new construction to a road construction package 3 weeks before the contract date. A crew of five used the program for the first time. They designed, slope-staked, and set reference points for the 3,500 feet of road in 2 days. The design included three draw crossings and 300 feet of full bench construction. The plan and profile plots were completed within 1 hour of office time. No delay occurred, and the contract requirements were met on time.

On the Deschutes National Forest, a crew of four surveyed, designed, and slope-staked 3,600 feet of road in a day using the HP-41cx program.

During the fall of 1987, a five-person crew from the Payette National Forest was detailed to the Stanislaus National Forest in Region 5 to field-design roads. The Stanislaus National Forest was preparing to sell about 200 million board feet of salvage timber from the 150,000-acre Stanislaus Complex Fire of 1987. The salvage timber sales were scheduled to be sold before the summer of 1988. The field design crew averaged 1/2 mile of road design per day, setting reference points, slope stakes, and clearing flags for each section. Plan and profile plots were done for each road, along with clearing and excavation quantities.

Program Description

The field-design program is easy to use. The program does not require a keyboard overlay for the HP-41. The calculator asks the designer for the needed information. Field design requires a survey crew leader with road-design experience. The crew sets the construction stakes as it goes. Only one trip over the line is needed, compared with two or more trips with traditional survey and design methods. Field design is an efficient way to do self-balance road design. Self-balance road design has a lower construction cost and less ground disturbance, compared with traditional geometric road design.

The program will self-balance cut and fill areas allowing for shrink, or it allows the designer to specify cut or fill at centerline. The cross-section information is limited to two sideslopes, uphill and downhill from centerline. The end areas of cut and fill, clearing width, and cut-at-centerline is stored in the extended memory of the HP-41cx, along with azimuth, grade, and distance between sections. This information is later transferred via a portable drive to a disk or cassette file tape. These files are then used for plotting the plan and profile.

The program allows the designer to check earthwork quantities between any given sections and to change any section to balance earthwork without redoing other sections. The program has the option of daylighting through cuts and fills. The cutslope, fillslope, road width, and shrink factor may be changed for any section. A printed record of all required input and slope stake information can be kept by using the HP thermal printer in conjunction with the HP-41cx. The program will take up to 120 sections before requiring the data to be transferred to a tape or disc file.

The plotting process begins by printing the data file and then editing any input errors that may have occurred. A program is then used to reduce and transfer the data back onto the HP-41cx for plotting. Another program is then used to plot the data using the HP-41cx and the HP 7470A plotter. The HP 7470A plotter produces plots on 8-1/2-inch by 11-inch paper. A copy machine can enlarge these plots to 11 inches by 17 inches with good results, or the plots can be used as is for inclusion in the contract package. See figure 1 for a sample plot.

Equipment & Cost

The cost of the electronic equipment required for the system is approximately $2,500. See table 1 for the list of equipment. The entire system is relatively portable. The printer, disk, and cassette drives run on rechargeable batteries. Only the plotter requires a 110-volt AC power source.

Conclusion

The field-design and plotting programs for the HP-41cx are an effective method for designing low-standard roads. The method is fast, and the roads are staked and ready for construction upon leaving the field. It works well for jobs where time is critical, such as roads for fire salvage timber sales. The method is less expensive than traditional methods of survey and design.

For further information, contact Mike Dixon at (208) 634-8151 or by DG at M.DIXON:R04F12A.

Table 1.—Equipment list.

Equipment	Price
HP-41cx	$ 249
Thermal printer (HP #82143)	385
Batteries (4 size N)	4
Extended memory modules (2) (HP #82181)	150
HP IL module (HP #82160)	125
Cassette drive (HP #82161)	550
or	
3-1/2-inch disk drive (HP #9114B)	595
Plotter module (HP #82184)	90
10 disks or cassettes	60
Graphic plotter (HP 7470A option 3)	711
Total retail price	$2,369

Note: The total price includes the disk drive and not the cassette drive.

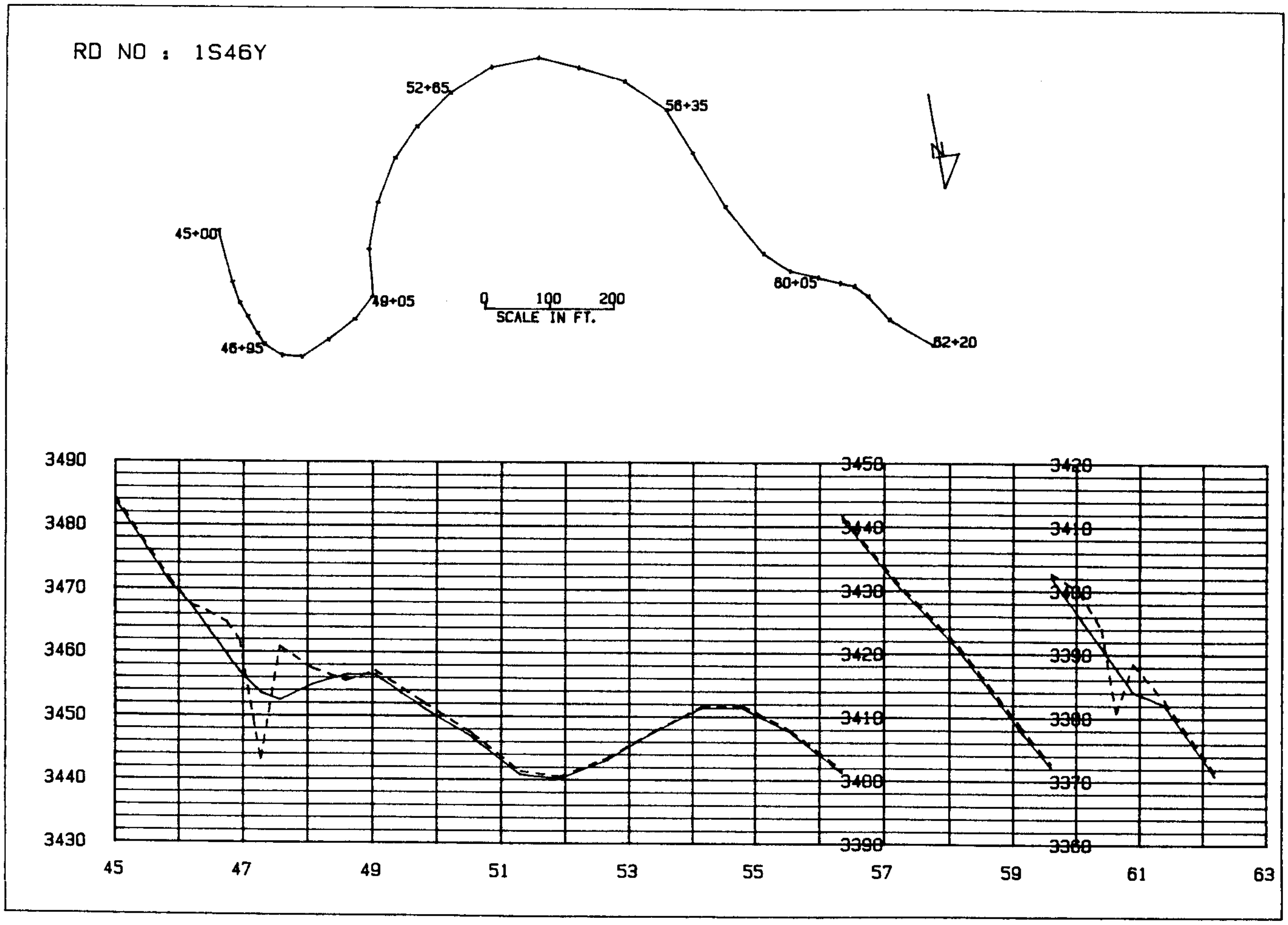


Figure 1.—Sample plot.

Low-Volume, Low-Cost Trail Bridges

Rick Ellison
Civil Engineer
Gallatin National Forest, Region 1

Introduction

The Livingston Ranger District on the Gallatin National Forest was in need of two new trail bridges to be installed on Passage Creek, near the northern edge but outside the Absaroka-Beartooth Wilderness Area. Fourteen thousand dollars had been allocated for the entire project and was targeted for a construction contract. Because of past bid history, Forest Service Engineers felt that the $14,000 might not be enough to build even one trail bridge. A decision to build the bridges with Forest Service employees was finalized.

Preliminary Preparation

The two bridge sites were 1-1/2 miles apart. Because of the rugged terrain between the two sites, materials could not be transported via this section of trail. The steep, narrow canyon walls prevented helicopter sling loads. A road through private land allowed vehicles within a half mile of the upper

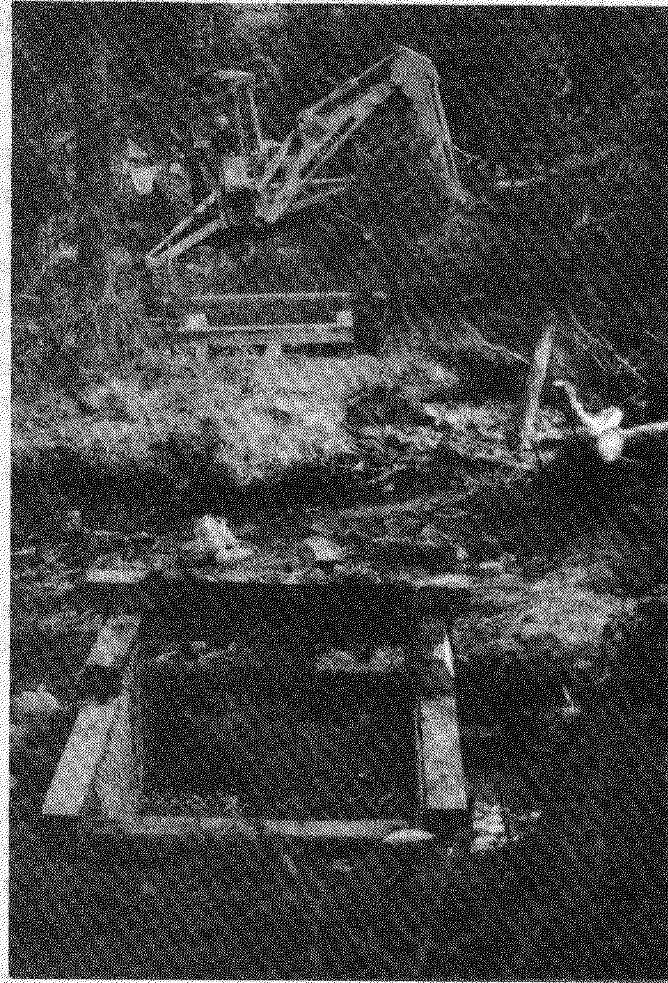
bridge site. The landowner granted permission to cross his land. The lower bridge site presented no access problems as it was less than 1/4 mile from the trailhead and had favorable topography.

Bridge Sites

Careful site selections provide the greatest potential for cost savings. The upper site was chosen where the stream banks were well defined and stable, yet close to the existing trail, eliminating excessive new trail relocation. The upper site was located perpendicular to the streambed. The site chosen also offered excellent nearby fill material for our abutment cribs and approaches. Span length needed was 30 feet for each site.

The new bridge at the lower site was constructed in the same location as the old bridge, which was removed. The alignment with the existing trail did not necessitate any new trail relocation. This site fit the criteria for the cost-effective bridge locations mentioned earlier.

Materials & Construction



The major cost savings in this project was brought about by the Forest Service using secondhand laminated bridge stringers salvaged from another forest road bridge. Region 1 Structures Engineer, Merv Erickson, examined stringers and found them to be suitable as a prefab deck and superstructure. These fully creosote-treated stringers were 60 feet long, 42 inches wide, and 14 inches thick. We cut two stringers in half, ending up with four 30-foot sections. Each 30-foot length weighed 4,000 pounds, which made handling difficult. Delivery to the trailhead was accomplished with a self-loading log truck. The two 30-foot sections, placed face down and side by side, created one 7-foot-wide, prefab bridge deck. This element of construction was a considerable time saver.

The abutment cribs were constructed with copper-sulphite treated 8 inches by 8 inches, predrilled, and pinned with 5/8-inch rebar. The lower bridge abutments were 6 feet high. The upper bridge abutments were 3 and 5 feet high. Abutment heights were determined by stream channel alignment, approach elevations, and high water line. A 9-gauge chain-link fence was installed and stapled inside the abutment cribs to prevent spillage of fill material. The cribs were filled with different gradations of rock, the largest of which was placed in the bottom. The decks were skidded onto the abutments and fastened in place with 3-inch angle iron and lag screws to the deck and abutments. The treated 4-inch by 4-inch curbing and rail posts and the treated 2-inch by 4-inch railing were secured with lag screws using an electric socket wrench powered by a gas generator.

One modification to the Region 1 Bridge Rail Plans was made to enhance the safety of pack-stock crossing the bridge. Two bottom rows of 2-inch by 4-inch railing were installed on each side of the bridges, with approximately 3-1/2 inch spacing above the 4-inch by 4-inch curbing and the same spacing for the second rail. This should prevent pack-stock from sliding off the deck as snow and ice build up in depth. Running plank consisted of three rows of rough-sawn fir 3 inches by 1 foot in staggered lengths.

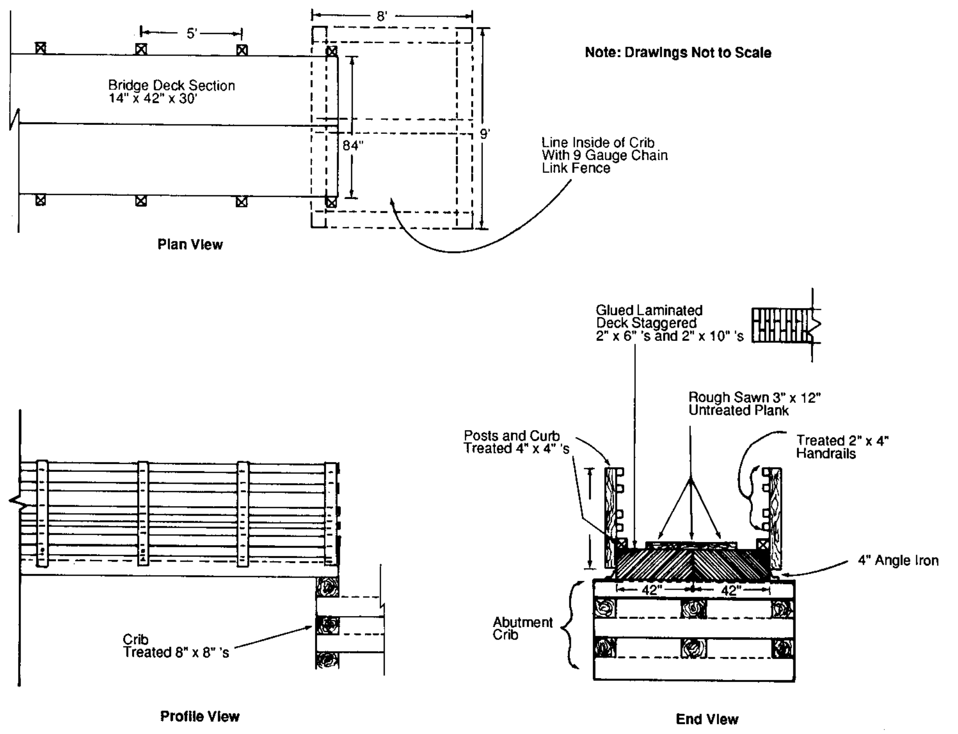
Construction Time & Cost

The total construction time of the two bridges was 20 days from start to finish, which included skidding the materials into the sites (3 days). We used basically a three-person crew, with one person operating equipment 75 percent of the time. Because of the narrow trail used for skidding materials, we needed to rent equipment with a very narrow wheelbase. The Ford 445 rubber-tired backhoe and John Deere 350 tracked crawler with a winchline filled those requirements. Small handtools, generators, and other equipment were transported via four-wheel all-terrain-vehicles.

The construction and material costs were as follows:

Materials	$ 2,600
Backhoe	1,760
Tracked crawler	450
Vehicle transportation	600
Labor	6,950
Total	$12,360

Actual savings were $1,640 under allocated project dollars. The estimated cost for two bridges was $28,000. There was no cost savings estimated for preparing and administering a trail bridge contract if we had chosen to go with a contract package. Note that the bridge decks were acquired at no cost. The total estimated cost savings to the Government were $15,640.



A Preventive Maintenance System at the North Central Forest Experiment Station

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WO-E Remarks

We appreciate the authors' sharing their Preventive Maintenance System with you. It is an excellent tool for use in facilities where several critical systems exist. One can think of preventive maintenance as insurance against higher costs. The majority of the costs are those associated with services interrupted by poor building performance and effective maintenance.

As the needs of most units vary considerably and most have some need for preventive maintenance at critical facilities, a two-pronged maintenance management system may be useful—one to track, prioritize, and implement condition-survey findings and the other, a preventive maintenance scheduling system such as the North Central Station model, to ensure that the rate of return on building investments is maximized by continuous "building benefits."

An important item stated in this article warrants special attention. Priority must be given to inspection. Separating operational inspection tasks from maintenance activities will allow the most critical maintenance work to be discovered.

Introduction

Mechanical, electrical, and specialty equipment at Forest Service Research Laboratories tends to be more complex than at other Forest Service facilities. To provide timely preventive maintenance for this equipment, the North Central Forest Experiment Station has developed a computerized Preventive Maintenance System. Preventive maintenance is simply defined as the frequently recurring types of maintenance procedures whose purposes are to ensure proper long-term operation, minimize operating costs, ensure a safe and healthy operation, and avoid premature and costly breakdowns. Preventive maintenance includes such procedures as inspecting for proper operation, cleaning, replacing filters, lubricating, and making periodic calibrations and adjustments. The key is that these procedures frequently recur and can be scheduled. In the North Central Station system, the term "preventive maintenance" does not include painting, roof replacement, major overhauls, or other, less-frequent maintenance procedures; that maintenance is done through one-time work orders generated either by a preventive maintenance inspection or through the building condition survey process.

The system, which is menu driven, is accessed through the Forest Service Data General Information System (IS), with data bases managed by the Data General, Data Base Management System (DG/DBMS). The input and output screens are generated by COBOL programs, CLI macros, and PRESENT macros. The North Central Station system for the Headquarters building includes 108 pieces of equipment and uses about 4,000 blocks of information and programming.

A Menu-Driven System

The following is a simple walk through the system using some sample screens and commentary. The logic, capabilities, and flexibility of the system should be apparent. When entering the system through the IS applications, we are presented with the screen shown in figure 1.

The work-order choice is the day-to-day heart of the system. It tells the maintenance worker what specific maintenance procedures to follow on a specific piece of equipment. However, before getting into the details of the work order it is necessary to explain where we get the work-order information. The work order is generated from a data base organized first by building system and then by an equipment name with a unique assigned number. The data base is built by the users themselves and is unique for each facility.

Building the Data Base

If we choose "2. Access/Update Data Base," from the figure 1 screen, we would see the screen in figure 2. Those major building systems that have been included in the North Central Station Headquarters preventive maintenance program have been categorized and given a system number 01 through 08. Other buildings may have other systems or system names.

As an example, if we choose "01 VENTILATION," we would then see the screen shown in figure 3, which lists those components of the ventilation system in the Headquarters building that require periodic maintenance. The "Pick one" choices at the bottom allow the normal View/Create/Edit/Delete options.

PREVENTIVE MAINTENANCE SYSTEM

What would you like to do?

1. Generate Work Orders.

2. Access/Update Data Base.

ENTER CHOICE: ____________

Figure 1.—First screen viewed when entering the system.

ACCESS/UPDATE PREVENTIVE MAINTENANCE DATA BASE

01 VENTILATION

02 AIR CONDITIONING

03 STEAM HEATING

04 PLUMBING

05 MISC. & LAB. EQUIPMENT

06 SAFETY

07 ELECTRICAL

08 TELEPHONE

Figure 2.—Access/Update Data Base screen.

Basic Equipment Inventory Data

If we pick "2. View Equip." from the screen in figure 3 and then enter 001 when it asks "Equipment Number?," we will see the screen shown in figure 4, which shows the basic inventory data for 001 supply fan #1. It is entered only once when the system is first started up and updated when major parts are replaced. Most of this information is not vital to the day-to-day operation of the Preventive Maintenance System; however, it can be useful for system trouble evaluations and for other management and design purposes.

Inspection & Maintenance

If we had chosen "1. Access Maint., etc." from the "Ventilation Equipment" screen in figure 3 and then entered "equipment 001" again, we would see the screen shown in figure 5. Choices 1 to 4 are specific data base records that contain information pertinent to supply fan #1. The inspection and maintenance records are similar to one another and are the basic data from which recurring work orders are generated. Inspection items only require verification that the equipment is operating properly; simple hand tools would be required for an inspection. A maintenance item would take longer and require more tools and materials. This distinction is clear in the literature on the general subject of preventive maintenance programs. When both maintenance and inspections are performed at the same time, the maintenance procedures are delayed and the inspections are never completed. If the inspections are not completed, the highest priority problems may not be discovered.

A typical maintenance item record for supply fan #1 looks like the screen shown in figure 6, which displays one of three separate maintenance procedures for 001 supply fan #1. The description entry is the work instructions that will be shown on the work order. The "Reference Number" is used only when more detailed instructions are required. It refers either to a separate

System Name: VENTILATION

Equipment Number	Name	Equipment Number	Name	Equipment Number	Name
001	SUPPLY FAN #1	002	SUPPLY FAN #2	003	SUPPLY FAN #3
004	RETURN FAN #4	005	EXH FAN #5	006	REST RM EXH #6
007	EXHAUST FAN #7	008	AXIAL FAN #8	009	EXHAUST FAN #9
010	EXHAUST FAN #10	011	EXHAUST FAN #11	012	EXHAUST FAN #12
013	EXHAUST FAN #13	014	EXHAUST FAN #14	015	AIR HANDLER 332
016	FUMEBLOWER 321A	017	FUMEBLOWER 331	018	FUMEBLOWER 329
019	FUMEBLOWER 532B	021	FUMEBLOWER 533	022	FUMEBLOWER 532A
023	ROLL FILTER #2	024	FLAT FILERS	041	SUPPLY DAMPER 1
042	SUPPLY DAMPER #2	043	RET EXH DAMPER 3	044	RET EXH DAMPER 4
051	VENT CLOCK #1	052	VENT CLOCK #2	053	DAMPER CLOCK
054	MIX AIR CONTR 1	055	MIX AIR CONTR 2		

Pick one:

(1.Access Maint., etc., 2.View Equip., 3.Create Equip., 4.Edit Equip.,

5.Delete Equip., 6.Select System, 7.Exit PMS)

Figure 3.—Ventilation screen.

CEO document that describes in detail the procedures or to a specific operations and maintenance manual in our hard-copy files. The comments also appear on the work order and can be useful for keeping track of the peculiarities of a certain piece of equipment.

These comments could be either a reminder to check a special feature or a special part number or a safety reminder pertinent to that piece of equipment. The "MM/YY A" array at the bottom of figure 6 is for scheduling. This system schedules only monthly scheduling. Maintenance required more frequently than monthly is routine enough that constant tracking and reminders are not necessary. By considering the seasons and the desired frequency, the month and year are entered left-to-right by rows. The "A" column represents "accomplishment." An "O" means that the procedure has not yet been done for that month and year. A "1" is entered when the

VIEW EQUIPMENT INVENTORY DATA	
01 VENTILATION	
EQUIPMENT NUMBER: 001 EQUIPMENT NAME:	SUPPLY FAN #1
ROOM NUMBER:	602
EQUIPMENT LOCATION:	WEST SIDE
SERIAL NUMBER:	63-056 3409466
MANUFACTURER:	BARRY US ELE
MODEL NUMBER:	245-DWD1XXXX
HORSEPOWER:	10
CAPACITY:	16,090 CFM
MOTOR RPM:	1,800
MAINTAINED BY:	WARN
VOLT/AMPERAGE/PHASE:	440/13.8/3
OTHER:	CFM AT 2"
OTHER:	
OTHER:	

Figure 4.—View Equip. screen.

procedure has been done; a "2" means that the procedure has not been done and was intentionally skipped. This reporting back and reentering takes some clerical time, but it allows better supervisory monitoring of actual accomplishments, especially if the work is being done under contract. The purpose of an inspection is to find impending or existing problems. These problems also are reported back and entered into the work-order system. Work to correct or avoid the problems is planned and scheduled, and a new "temporary," one-time work order is created. Once the work is reported as "accomplished," the temporary work order is dropped from the system.

Monitoring Record

A typical monitoring record looks like the screen shown in figure 7. We have not yet instituted the monitoring part of our program. In contrast with simple preventive maintenance, certain types of monitoring allow some "predictive" maintenance.

EQUIPMENT DATA BASE

01 VENTILATION

001 SUPPLY FAN #1

1. INSPECTION
2. MAINTENANCE
3. MONITORING
4. REPAIR HISTORY
5. RETURN TO PREVIOUS MENU

Figure 5.—Access Maint., etc., screen.

Monitoring for predictive maintenance can take many forms, including readings from operation counters, hour meters, pressure levels, amperage readings, vibration readings, or any number of factors that may "predict" impending trouble. Monitoring can also be a simple observation of the smoothness of an operation. Given a history of appropriate observations or readings, sudden changes can be predictive. These readings would simply be added to the inspection procedure and reported back along with accomplishments.

Repair History Record

The repair history record is similar to the monitoring record and shows the major maintenance procedures performed, data completed, costs, work hours, and comments. This information can be entered manually as work occurs but also will be updated automatically as one-time temporary orders are reported as accomplished. Recurring work orders are not included because they are routine and would clutter up the significant information contained in the repair history record. The repair history record is useful for a number of management functions, such as determining high maintenance costs, deciding when equipment is due for replacement, detecting recurring operational or design problems that need to be corrected, and planning for future major budget items.

Recurring Work Orders

With the building systems, equipment listing, inventory data and inspection, maintenance, monitoring, and repair history records all entered into the data base, the preventive maintenance system is ready to generate recurring work orders. If we go back to the screen shown in figure 1, we will see that work orders are generated by the maintenance mechanic. The mechanic accesses the system once each month and prints out the work orders for that

VIEW MAINTENANCE RECORD

01 VENTILATION

001 SUPPLY FAN #1

MAINTENANCE ITEM

NUMBER: 03

DESCRIPTION:

LUBRICATE MOTOR AND FAN BEARINGS (4 FITTINGS)

REFERENCE NUMBER: XXXX

COMMENTS:

1. DO EVERY 6 MONTHS?

2. IS THE RIGHT BEARING STILL SQUEAKING?

3. USE GENERAL DUTY GREASE?

MM/YY	A	MM/YY	A	MM/YY	A	MM/YY	A
10/86	0	04/87	1	10/87	0	04/88	0
10/88	0	04/89	0	10/89	0	04/90	0
10/90	0	04/91	0	10/91	0	04/92	0

TOUCH NEWLINE TO CONTINUE

Figure 6.—Item record screen.

month. The St. Paul Headquarters Building has from 5 to 68 work orders per month, depending mostly on startup demand and maintenance of seasonal equipment.

A typical recurring work order looks like the screen shown in figure 8. The work order tells the maintenance worker what to do for a particular piece of equipment, tells where the equipment is located, and gives references and comments pertinent to that particular piece of equipment.

Temporary Work Order

During either an inspection or a simple maintenance procedure, the maintenance worker may notice the need for additional, more involved work. That work is reported on the bottom of the recurring work order, stating what needs to be done, any special part required, when it should be scheduled, and any special comments pertinent to the required work. The clerk then

VIEW MONITORING RECORD

01 AIR CONDITIONING

001 EQUIPMENT NAME

MONITORING ITEM

NUMBER 99

MONITORING DESCRIPTION: XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

COMMENTS:

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

MM/YY	VALUE	MM/YY	VALUE
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99
XX/XX	99999.99	XX/XX	99999.99

Figure 7.—Monitoring record screen.

enters a temporary work order into the system. When the scheduled performance date comes up, the temporary work order is printed along with the normal recurring work orders for that month. The maintenance worker reports when the work has been completed, the temporary work order is dropped from the active system, and the repairs are added automatically to the repair history record.

1/30/87
PREVENTIVE MAINTENANCE WORK ORDERS

System Name: VENTILATION

Equipment Number: 001 Equipment Name: Supply Fan #1

Room Number: 601 Equipment Location: East Side

INSPECTION

Number: 1

DESCRIPTION:

Check operation, belts, belt tension. Note unusual sounds, vibrations, etc.

REFERENCE:

COMMENTS:

1. Is water condensing in fan enclosure?

2. "Replace Drive Belts" Is maintenance Item #1 (2 belts - size 144)

3. Do every 3 months

Due Date: 7/87/0

Current Status: Not done

Date Last Performed: NOT AVAILABLE

Create Temporary Work Order?

Description: ______________________________

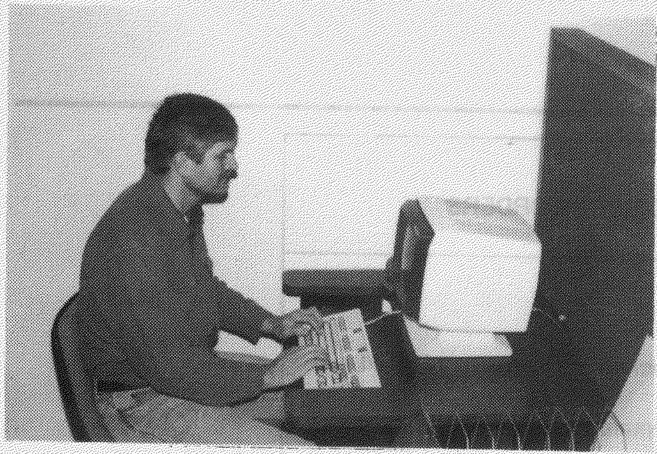
Date Scheduled: mm/yy

Comments:

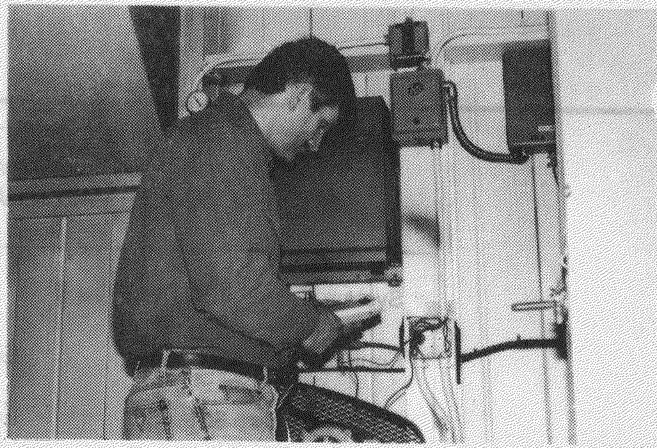
1. ____________________

2. ____________________

Figure 8.—Work order screen.



The generation of work orders is done by maintenance mechanics. They access the system once each month and print out the work orders for that month.



Monitoring for predictive maintenance could take many forms. It could be readings from operation counters, hour meters, amperage readings, or any number of factors that may be predictive of impending trouble.

Conclusion

The major portion of the North Central Station system has been in operation at the North Central Station Headquarters Building in St. Paul, Minnesota, since January 1987. Not all the building systems are fully inputted, and the monitoring and repair history records are not fully operational. We will add to our system as time, need, and opportunity allow and will extend it to cover all major facilities at the North Central Station. We first wanted to test the system and modify it as needed before investing the time necessary for its full implementation. We have modified the system several times and have more improvements planned.

The entire exercise and the resulting system have resulted in numerous benefits, both expected and some unexpected. We found that we did not have a common understanding of what preventive maintenance is.

We now have a specific list of necessary procedures and have found that it is not as complicated and mysterious as we had thought. For some months, the work-order listing looked somewhat daunting, but when approached in a systematic way, it did not take as long as we expected. While researching for some of the procedures, we found that we knew just about all the preventive maintenance procedures for some pieces of equipment, especially those that had given us breakdown trouble before. We also found that we had totally ignored those pieces of equipment that had performed uneventfully. A little timely, extra care can ensure further trouble-free service. Of course, the major benefit of a formal preventive maintenance program is that simple, high-payoff maintenance procedures are not forgotten. The hope is that, instead of continually responding to breakdown emergencies, our time and effort can be expended to prevent breakdowns and save money. EFN

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Errata

In your copy of *Engineering Field Notes*, May-June 1988, "Space Shuttle Large Format Camera Photography in Resource Management" (pp. 15–26), please note that the captions for figures 4 and 5 were mistakenly switched.

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