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ASNAP: Administrative Site Needs Assessment Process

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In November 1980 and January 1981, an Engineering Program Review was conducted by Dick Deleissegues, Assistant Regional Engineer; Larry Hornberger, Los Padres Forest Engineer; Paul Stutes, Regional Office Staff Engineer; and Nancy Varga, Management Analyst, Regional Office Engineering Staff. Their findings regarding facility maintenance showed a deficiency in the program that was currently in use. The team presented several alternatives to the problem. The preferred alternative involved an analysis that would help the setting of conscious goals, objectives, and priorities. The preferred alternative also stated that the elimination of stations should be an integral part of the analysis. This preferred alternative was the beginning of the administrative site needs assessment process (ASNAP).

The ORIGINS of ASNAP

ASNAP was developed between December 1982 and April 1985. To start, in December 1982, representatives from several Districts, the Supervisor's Office, and the Regional Office in Region 5 held a workshop at which the framework for ASNAP was developed. This framework included a workload analysis, a workforce analysis that recognized a range of options between all force account to maximum contract, the determination of location of work, the identification of needed facilities, the determination of alternatives for providing needed facilities that do not exist, and the identification of unneeded facilities. A prerequisite to determining facility needs included the need to establish firmly the Forest's posture on providing employee housing.

Subsequent to the original workshop, the Forest developed a written guide for completing the process. This guide was the basic direction used in a series of workshops held between January and June 1984. Workshops were held on each of the five

Ranger Districts in Region 5, with participation by members of Fire, Recreation, Engineering, and other interested Staffs. During these workshops, the process continued to evolve as each District's ideas were incorporated. After the District workshops were completed, two more workshops took place in the Supervisor's Office with the Forest Recreation and Fire Staff Officers and the Forest Engineer as the key participants. These workshops consolidated and refined the Districts' recommendations and addressed the Supervisor's and Forest-wide concerns.

Leased space was not evaluated as a part of this study, with the exception of the Ojai District Office, where the construction of a new office to replace the existing leased office was included as a new construction project.

ASNAP'S GOALS

The goal of ASNAP is to develop a facilities program that meets identified needs within existing budgets and personnel ceilings. The specific objectives of the process are as follows:

(1) Develop a housing policy.

(2) Develop a construction/acquisition policy for new facilities or replacement facilities. List projects by priority.

(3) Develop a maintenance policy for existing facilities. List all buildings by priority ranking for maintenance. Include money needed for the maintenance program.

(4) Develop a disposal policy for facilities identified as unneeded or incapable of being properly maintained.

ASNAP is an original analysis of the problem of setting priorities for building maintenance and construction/acquisition projects and of identifying and disposing of unneeded buildings. ASNAP also complies with the direction in FSM 7312.1 for a Facility Master Plan.

The Engineering Staff involved in facility maintenance are pleased with ASNAP and feel it will improve the facilities program, especially in these days of diminishing funds. The five District Rangers in Region 5 are also very pleased with ASNAP and have approved its implementation.

The primary champions of the administrative site needs assessment process are Larry Hornberger, Los Padres Forest Engineer; Paul Greenfield, Civil Engineer, Angeles National Forest; Joseph Olson, Civil Engineer, Pleasant Hill Engineering Center; Lynn Kanno, Civil Engineer; and Gilbert Levesque, Civil Engineering Technician.

Any questions regarding ASNAP may be directed to Larry Hornberger, Forest Engineer, Los Padres National Forest, 6144 Calle Real, Goleta, California 93117, phone 960-7768 FTS or (805) 683-6711, extension 768.

WASHINGTON OFFICE COMMENTARY

Congratulations to the Los Padres Staff for developing and sharing ASNAP. We concur with its use in analyzing the needs to be incorporated in the Facilities Master Plan. This plan has been established as the principal working tool for each unit of the Forest Service in its Facility Management Program. Expanded direction on plan content is found in FSH 7309.11, Chapter 11.2.

The ASNAP works particularly well in analyzing alternative management styles, staffing levels, and skill deployment and in determining the facilities necessary to accomplish each alternative. This is one of the more demanding steps in facility master planning. The process is being used widely in Region 5 and other units.

We encourage readers to send us their comments on ASNAP and other facility planning processes so we may share your efforts and experiences with others. EFN

Device To Measure Road Dustiness— 1985 Summer Field Evaluations

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The acceptability of the dust level on a road depends on the type of use, the maintenance level, and the importance of the road (as measured by traffic volume). These factors, along with others such as safety, aesthetics, and aggregate replacement costs, are usually considered when making a decision of whether to use a palliative for dust control. It is possible that, within a given Forest, two roads may have identical levels of dustiness, but due to the above factors, one road would receive palliation while the other would not.

OBJECTIVES

During the summer of 1985, our work continued with the development of a Road Dust Monitor (RDM), an improved version of the model that was field tested in the summer of 1984. The device consists of an infrared sensor that mounts behind the rear tire to measure air opacity and a small instrumentation package which rests on the dashboard to display the readings. The RDM was described more completely in the May-June 1985 issue of Engineering Field Notes.

Our efforts focused upon validating that the instrumentation functions effectively for the variety of road materials found in the continental United States in the National Forests. A major interest was to obtain a larger data base on the tolerable level of road dustiness, which will in turn provide the information needed to further refine the RDM and to define a multi-Regional "Opacity Index." The Opacity Index is the percent of time that the air opacity exceeds a tolerable level for a section of road.

FIELD LOCATIONS

Twelve National Forests were selected in consultation with the Washington Office Engineering Staff as sites for field testing of the RDM. Soil type and climate information were mapped and locations were chosen to represent the widest variety of possible geomorphological conditions. The following is an alphabetical list of the twelve Forests where field testing was conducted:

(1) Angeles National Forest.

(2) Cherokee National Forest.

(3) Clearwater National Forest.

(4) Homochitto National Forest.

(5) Ouachita National Forest.

(6) Roosevelt National Forest.

(7) Santa Fe National Forest.

(8) Siskiyou National Forest.

(9) Stanislaus National Forest.

(10) Superior National Forest.

(11) Willamette National Forest.

(12) Winema National Forest.

Comments were received from a total of 48 personnel from the twelve National Forests visited. They represent a wide variety of people--from Forest Engineers and Regional Materials Engineers to non-Forest personnel like campground hosts and campers.

INSTRUMENTATION EVALUATION

The instrumentation evaluation was typically a two step process consisting of an initial training session followed by a debriefing session 2 weeks later. During the first visit, an informal interview was conducted with Forest Service personnel to explain the project objectives and to obtain information on the history of dust palliative use. The instrumentation was then installed on a Forest Service ½-ton pick-up truck.

The roads to be tested were preselected by the local Forest Service contact person. They represented both barely tolerable levels of dustiness and the widest possible variety of soil types. Training for the operation of the equipment was conducted on one of these roads. Individuals trained to operate the instrumentation were asked to involve a wide variety of people. Participants were asked to give their opinions regarding the panel meter reading which defined the dust level that would be barely acceptable if the road had a Level 3 maintenance standard with mixed logging and recreation traffic. (Note that the road actually tested may have had a different standard and use, but it was thought of according to the above criteria.)

After approximately 2 weeks, each Forest was revisited to debrief individuals involved in the field testing of the RDM. Soil samples and weather data were collected for later analysis.

It was learned that the RDM would work satisfactorily with the wide variety of different soil types that were encountered. One of the most interesting findings that came from the Summer 1985 study was the fact that people all over the country defined approximately the same level of air opacity as being unacceptable.

USEFULNESS of the INSTRUMENTATION

In all locations, the need for a repeatable method for monitoring levels of dustiness was recognized and in all instances the prototype RDM was received very favorably. However, opinions regarding the usefulness of the instrumentation varied among the Forests, depending upon the activity level (for example, heavy timber haul versus recreation traffic). Possible uses identified for the instrumentation included:

(1) In Forests currently using dust palliatives or intending to in the near future, the instrumentation can help to test the effectiveness of various types of palliatives in a Forest and to determine the quantity needed.

(2) On timber haul roads, the instrumentation could help to settle disputes regarding when to apply palliatives.

(3) Where speed reduction is used for dust control, the instrument can help determine the appropriate speed limit for an acceptable level of dust.

(4) The instrument may lead to a more uniform road condition with regard to dustiness from one District to another and from one Forest to another.

CONCLUDING REMARKS

Overall, all participating National Forests were very cooperative. Valuable comments and suggestions were made and are being incorporated into the final design of the instrumentation. The energy expended in conducting field evaluations in 12 locations across the continental United States was well spent. It was evident from the field tests that changes in both soil types and weather conditions have a noticeable effect upon the level of road dustiness. The tests showed that the present design of the RDM can adequately deal with the variety of conditions that were encountered. From the interviews, we learned that most people across the country define the same level of air opacity as being unacceptable. Modifications of the mounting bracket for the infrared sensor and refinements in the calculation of the Opacity Index are now being studied. The authors greatly appreciate the enthusiastic assistance that was so generously offered to us by the Forest Service personnel across the country. We thank you for your help. We believe your suggestions will yield a better RDM device and will ultimately result in better road dust management procedures in the Forest Service.

Keeping Beavers From Plugging Culvert Inlets

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The PROBLEM

Where indigenous, beavers are found in areas with an abundance of water and trees. Their propensity for building dams--unique among animals--is well known. Busy beavers within National Forests can be a headache for road maintenance crews because one of the easiest ways for a beaver to build a dam is simply to plug the inlet of a culvert. A plugged culvert often results in a washed-out road. Unplugging the culvert can take a considerable amount of labor and equipment. And, besides, by the morning after clearing a spot, the culvert usually is completely blocked again. At sites where beavers are active and detailed cost records have been kept, the average cost to keep a culvert cleared of a beaver dam is approximately $800 per year.

Because of this persistent problem, the San Dimas Equipment Development Center (SDEDC) was asked to evaluate existing methods or develop new ones for keeping beavers from building dams at culvert inlets. Each approach that was investigated hinged on one of two traits characteristic of beavers:

(1) They normally do not try to plug a culvert if the area to be plugged is very much greater than the culvert opening itself.

(2) They usually will not try to plug an opening through which water flows vertically upward.

SOLUTIONS INVESTIGATED

On the Ottawa National Forest in northern Michigan, SDEDC tested four different methods for keeping beavers from plugging culvert inlets. The equipment used in these methods included perforated pipes, perforated culverts, downspouts, and bafflers. These primary approaches, usually installed in conjunction with a secondary backup approach, were put in place in the summer of 1983.

The Perforated Pipe Method

The perforated pipe method consists of laying a piece of the pipe with one end inside the culvert inlet and the other end extending upstream, well beyond the culvert entrance. A cap or plug must be installed on the upstream end of the perforated pipe. The theory here is that, although beavers might build a dam in the culvert entrance, water can still flow into the pipe through the perforations and then out the end of the pipe downstream of the dam. Beavers might plug some of the perforations but they usually will not get them all.

To allow for a large enough volume of water flow, it may be necessary to use more than one pipe or to put a "Y" or "T" in the pipe upstream of the culvert so that extra arms of perforated pipe can be installed. The pipe or pipes can rest on the bottom of the culvert interior but should be supported--by a stake or a cross-bar between two stakes--above the bottom of the stream or pond.

As an additional step, a baffler or fence (constructed of 12½ gauge wire-mesh fencing well supported with stakes) can be built around the culvert entrance; the perforated pipe or pipes should be passed through a hole in the fence. Then, the beavers have to build their dam against the fence, where it is much easier to remove than if it were built inside the culvert.

The Perforated Culvert Method

The perforated culvert method consists of adding a short length of a specially designed, same-diameter culvert, as shown in figure 1, onto the end of the culvert already in place. The theory here is that

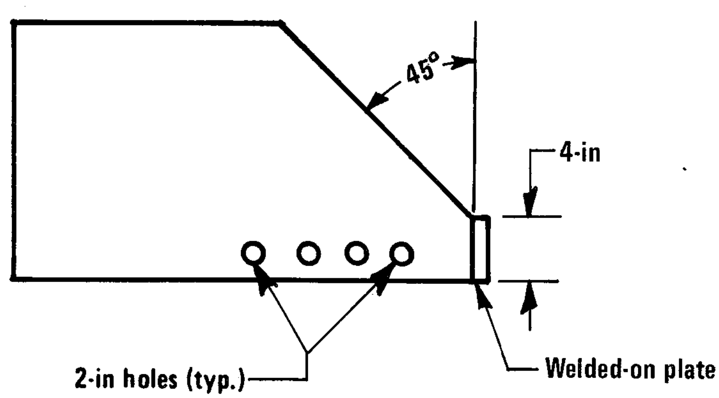

Figure 1.--Perforated culvert approach.

water will flow vertically upward through the holes cut into the bottom of the attachment. Beavers do not plug these holes, but if they should become plugged or if the flow of water increases greatly, water can flow into the end of the culvert extension as soon as the water level rises over the 4-inch welded-plate lip. Further, steel mesh or bars can be welded over the sloping opening to keep beavers from crawling into the culvert for dam-building purposes.

The Downspout Method

The downspout method consists of cutting a section of culvert at a 45-degree angle and welding this piece back to form a 90-degree angle, as shown in figure 2. When this is attached to the in-place culvert with the right-angle section pointing downward, water must rise vertically to flow through the culvert. The attachment should be installed to extend downward as far as possible without picking up debris from the bottom of the stream or impoundment. Again, steel mesh or bars should be welded across the opening to prevent beavers (or large debris) from getting inside.

The Baffler Method

The baffler (or fence) method of preventing beavers from reaching culvert inlets can be tried at locations where a fast-flowing or a shallow stream precludes other approaches. First, on the upstream end, construct a box fence around the culvert opening. Then, extend two parallel fences, 3 feet apart, upstream from the box fence for approximately 30 feet and join their ends together. Fabricate the fences from $12\frac{1}{2}$-gauge wire mesh with approximately 4-inch openings. Support the fences on steel posts driven at least 3 feet into the stream bed. Now, to construct a dam, the beavers would have to plug the baffler along its entire length; usually they will not attempt this.

The specific method to be used at any site depends upon such conditions as the flow rate and depth of the water. The specific design of the approach must take into consideration hydraulic efficiency to ensure that full water flow will be accommodated.

RESULTS OBSERVED

After monitoring the Ottawa National Forest sites for a year, SDEDC observed the following pertaining to each approach that was tried. At the site with perforated pipes and a fence built around the culvert, beavers had built a dam around the fence. The perforations in the pipes were still open. However, there was a pond behind the dam and no

Figure 2.--Downspout approach.

water was flowing in the pipes because of the low water level. The culvert under the road was free of any debris. Overall, the installation was performing as designed, and no maintenance was required.

The perforated culvert installation had fallen off and been replaced by a larger extension. While the culvert was not completely plugged, there was debris in it that was probably placed there by beavers. For this approach to work properly, the maintenance crew would have to clear out the debris and then re-attach the extension.

At the downspout (right-angle attachment) site, the culvert was clear of debris, and there was no sign of any beaver activity. Also, there was no beaver activity at the baffler location. Grass and leaves were lodged against that part of the fence around the culvert; the fence was partially down. The fence extending upstream was working properly. The only maintenance needed would entail reinforcing the fence around the culvert.

RECOMMENDATIONS & FURTHER ACTIONS

The downspout approach shows great promise and should be tried at National Forest culvert locations that have beaver problems. The perforated pipe approach has succeeded at several locations on different National Forests; the baffler approach shows potential for culverts larger than 5 feet. The perforated culvert extension also might work at some sites.

Please contact SDEDC for design details on any or all of the four approaches presented here. Also, please notify SDEDC of any field experience you might have with the systems described here or with any new concepts that are being tried.

The Mammoth Alternate Exit Road Aerial P-Line Survey

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Region 5

BACKGROUND

Mammoth Lakes, California, is a busy resort town within the Inyo National Forest on the east side of the Sierra Nevada Mountains. Recently, it has received national attention because of seismic and volcanic activity in the area. If there is a major earthquake or eruption, it might be necessary to evacuate tens of thousands of people from this area.

California State Route 203 is the only highway from Mammoth Lakes to the outside world. It connects with U.S. Route 395, which is about 3½ miles to the east. Because of its location, Route 203 probably would be impassable after an earthquake or eruption, thus isolating the town. In January 1983, the area was rocked by a series of 5.6-magnitude earthquakes, which prompted a decision to build a second highway, in a different location, connecting Mammoth Lakes and U.S. Route 395. It would be a two-lane, paved road approximately 6 miles long. The Forest Service took the lead role in this project, making a commitment to have the road planned, designed, constructed, and open to traffic by the end of the 1983 field season. This allowed 10 months for the completion of the road from start to finish.

PLANNING

Only a general corridor for the road had been selected when the decision to build the road was made. To advertise a construction contract, the precise location would have to be selected and a P-line survey (horizontal traverse, centerline profile, and cross-sections) completed in order to design the road and to estimate earthwork quantities. However, the entire area was covered by a blanket of snow more than 10 feet deep. If the location and survey work were delayed until the ground became accessible (May or June), there would not be sufficient time to complete the project by the end of the season.

On March 8, 1983, Regional and Forest Engineering and Contracting Staffs held a meeting. The calendar of events for the preconstruction phase of the project was established on that day. All topographic data would be collected by aerial survey methods. The Geometronics Staff was given until March 21 (12 calendar days) to provide topographic maps of the corridor and an aerial P-line survey of the final location.

AERIAL PHOTOGRAPHY

Because of the heavy snow cover, all photogrammetric work had to be done using existing materials and data. All Federal, State, and local agencies were searched for materials. The best aerial photography available from any agency was 11-year-old Forest Service resource photography at an average scale of 1:18,500. Of these, 59 exposures were selected to cover a wide area around the project in case a drastic change in location might be required later.

A set of contact prints and film diapositives for mapping were ordered by telephone from the USDA Aerial Photography Field Office in Salt Lake City, Utah, on March 8. These materials arrived in San Francisco by Federal Express less than 44 hours later. Immediately upon their arrival, Engineers from the Forest and specialists from Geometronics worked together to define the boundaries of the area to be mapped.

GROUND CONTROL

Snow again was a problem when it came to providing ground control points for the aerial photography. Image points that could be identified on the photos could not be found and surveyed on the ground. Once again, complete reliance on existing materials was necessary.

The California Department of Transportation (Caltrans) had a number of horizontal and vertical control points in the town of Mammoth Lakes and along U.S. Route 395. They were on the State plane coordinate system with sea-level datum for elevations. Aerial photographs and maps showing these points were flown to San Francisco from the Caltrans office in Bishop on March 11.

Three of the points were in usable positions for the project. They were transferred from the Caltrans contact prints to the Forest Service diapositives using a Wild PUG-4 zoom point marking instrument. In one case, the image of a Caltrans target could actually be identified on the Forest Service photographs. In addition, two photo-identifiable spot elevations shown on 1:4,800 scale, 20-foot contour interval Caltrans project maps were used as vertical control points.

Six additional horizontal-vertical control points were derived from the Forest Service Primary Base Series quadrangle maps and orthophotos. These maps had been compiled at 1:48,000 scale with 80-foot contours in 1953 by the U.S. Geological Survey. The orthophotos were produced at 1:24,000 scale by the Forest Service in the mid-1970's. Images that could be identified on both the aerial photographs and the orthophoto negatives were selected as control points. They then were digitized from the orthophoto negatives using a 0.001-inch resolution two-axis digitizer and transformed to State plane coordinates, placing them on the same datum as the Caltrans points. Elevations were interpreted from the topography shown on the maps.

With this mixed bag of control points, a fully analytical aerotriangulation was used to control an 11-photo block. All control points, tie points, and pass points were marked on the diapositives with a Wild PUG-4. The diapositives then were measured on a kern MK2 monocomparator. The computations were made using the programs ICRAST and GIANT at the Fort Collins Computer Center. The block adjustment was weighted very carefully to allow a statistically proper distribution of ground control error among points with vastly different reliabilities. The aerotriangulation was done on Friday night and Saturday morning, March 11 and 12.

MAPPING CONTRACT

Completing 6 miles of topographic mapping and cross-section measurements within the required timeframe was beyond the in-house capability of the Geometronics Staff in Region 5. Specifications were prepared on March 10 so that a contract could be awarded for this work.

Three contractors accepted invitations to a prebid meeting in San Francisco on the morning of March 11. The job materials, specifications, timing, and coordination requirements were discussed in detail at this meeting. The contractors were asked to submit their price quotes by telephone before 4 o'clock that afternoon. The work was awarded to Towill, Incorporated, of San Francisco, for $2,335 before the close of business that day.

TOPOGRAPHIC MAPPING

Maps were prepared for a 6-mile-long, 1,000-foot-wide corridor at 1:2,400 scale with a 10-foot contour interval. They were compiled out of five stereo models by Towill, using two Wild A-8 stereoplotters. To save time, each stereo model was compiled on a separate manuscript sheet instead of the more traditional approach of combining several models on one sheet. This enabled the two instruments to work on adjacent stereo models simultaneously. A short band of contours was traced from one manuscript to the next so that the operators could match the edges of the sheets.

The original pencil manuscripts were used as the final map sheets. The pencil work was intensified on the index contours and on selected features for readability. Each sheet was dressed up with a title block, north arrow, bar scale, sheet index diagram, and other details normally found on drafted maps. All sheets were kept extremely neat and clean during compilation, resulting in a very satisfactory appearance.

CROSS-SECTIONS

The two Wild A-8 stereoplotters also were used to measure cross-sections along the P-line. A herringbone template, registered to the P-line on the map manuscript, was used to guide the operators across each section from left to right as points were measured directly in the stereo model.

Each cross-section point was measured and automatically recorded in the arbitrary coordinate system of the stereoplotting instrument. A three-dimensional coordinate transformation, based on the control points in each model, then was used to compute State plane coordinates and sea-level elevations for each point. Towill delivered the coordinate data to the Forest Service on magnetic tape. A program named XSEC on the Fort Collins computer was used to convert the data from coordinates to elevation/distance and rod/distance formats. Hard copy listings and RDS-compatible computer files (Record Types 11 and 50) were produced for the Road Design Engineers. Towill also delivered a profile plot of each cross-section.

A total of 326 sections were measured at 100-foot intervals, plus terrain breaks and PIs along the P-line. The sections averaged 24 points each, extending to 500 feet each side of the centerline.

Extremely close coordination between Geometronics and Towill was necessary during the contract. Towill could not measure cross-section data until the P-line was designed by the Forest Service, which, in turn, could not be done until the topographic mapping was completed by Towill. Thus, each time one or more stereo models of mapping had been completed by Towill, the Geometronics Engineer administering the contract would visit Towill's offices and design another segment of P-line directly on the map manuscripts. This "while you wait" approach to road design was very efficient since it enabled Towill to leave some models set up in the stereoplotters while the P-line was being designed. Cross-sections then could be measured without having to waste time setting those models up twice.

PROJECT COMPLETION

Towill delivered the completed topographic maps and cross-sections to the Forest Service on time, Monday morning, March 21. By midafternoon, the materials were flown to the Supervisor's Office of the Six Rivers National Forest in Eureka, California, where the road would be designed. Construction began on June 20 and was completed 32 days ahead of schedule on October 7, 1983. The difference between the estimated and "as built" earthwork quantities was 15 percent.

This was a highly successful project, and it is important to take special note of some of its details:

(1) The site was ideally suited to photogrammetric mapping and measurement by virtue of its topographic and vegetation characteristics.

(2) Even though the source materials could be considered marginal, the application of sound and rigorous photogrammetric principles resulted in quality products.

(3) Work of this urgency was contracted for. The contract was administered very closely, both by telephone and in person. The COR was in Towill's office on 5 of the 8 days of the contract. On only 2 days (Saturday and Sunday) was there no contact at all.

(4) Highway engineering skills were available in the Geometronics Staff. This enabled decisions related to the road design to be made on the spot during the photogrammetric phase of the project. These decisions otherwise might have been referred to Engineers from other Regional Office Staffs or on the Forest, resulting in delays.

Finally, and most important, was a spirit of willingness on the part of both the Forest Service and Towill to do the job right and complete it on time.

Using HP-41C for Preliminary Road Cost Estimation

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Thomas A. Durston
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Region 6

This report documents a road cost-estimating program written for the HP-41C calculator. The program produces cost estimates for excavation, clearing, grubbing, seeding, ditch relief culverts, drainage crossings, and surface rock. It is sensitive to road design standards and can be used to evaluate various alternatives effectively.

INTRODUCTION

In the early stage of transportation planning, route selection requires quantity and cost estimates for economic analysis. The accuracy and consistency of these estimations can be a vital factor in choosing the most economical route. However, accurately estimating road construction costs may be an involved and time-consuming process. Construction costs are a major concern in Forest roads. An efficient, quick-response method for estimating construction costs is needed.

Traditionally in the Forest Service, the preliminary construction costs have been estimated through the use of historical bid data for unit costs and the use of graphs, tables, and nomographs to estimate quantities. These traditional cost-estimating methods have been less sensitive to variation in design standards and terrain and have been somewhat cumbersome and time-consuming to use.

To overcome the shortcomings of traditional estimation methods, Engineers of the Willamette National Forest in Eugene, Oregon, developed a computerized estimation method based on semiempirical quantity estimates and a cost matrix. A construction quantity matrix was constructed by computing quantities based on the RDS designer's aid program for 17 preselected subgrade templates on 8 slope classes applying a set of adjustment factors derived from local experience. The estimation procedure is embodied in a computer program called Road Cost, which was developed and published by Engineers at the Willamette National Forest.

Although this method may reduce computation time and increase accuracy when compared with traditional approaches, it does not allow sufficient flexibility in the choice of design parameters, such as construction slope ratios and amount of turnouts. Also, for application in different areas, a new construction quantity matrix should be developed by using adjustment factors for local conditions. Thus, the Willamette method is limited in terms of its spatial transferability.

This paper presents a simplified analytical method for estimating road cost by using the program as written for the HP-41C calculator. This analytical method overcomes the problems of flexibility and transferability that were inherent in the Willamette version. The applicability of the method was demonstrated by several case studies in the Gifford Pinchot National Forest in Washington State. The results of these studies were compared with estimates made by a traditional approach and with the final actual quantities and costs as computed in the design.

PROGRAM DEVELOPMENT

This cost estimation approach develops a calculating procedure that can be applied to various types of roads, including single-lane roads with and without turnouts and multiple-lane roads. The basic approach is based on generating a typical template that is assumed to be uniform except at drainage crossings. Design assumptions are patterned after those made in the Forest Service Road Design System (Engineering Computer Application Handbook, 1981).

The program is oriented towards single-lane roads and computes quantities and costs based on lane and turnout road widths and the percentage of road taken up by turnouts. Quantities and costs also may be calculated for double-lane roads or single-lane roads without turnouts by specifying no turnouts in the program. Quantities considered in the procedure are excavation, haul, clearing, grubbing, seeding, ditch relief culverts, drainage crossings, surface rock, construction surveying, and mobilization.

Excavation quantities are computed based on a typical full bench or self-balanced section. The program also considers the excavation volume necessary to construct throughfills specified in the drainage crossing subroutine. The compaction factor is treated as a variable in the self-balanced section estimation. Figure 1 shows the typical sections and the variables used. As shown in figure 2, clearing is to run from a specified upper limit to the toe of fill.

Figure 3 illustrates the grubbing area. Grubbing is required from top of cut to the toe of fill if the fill depth is less than or equal to 2 feet (0.61 meters) or if, on larger fills, the fill depth exceeds 2 feet (0.61 meters). Seeding area is taken to be the area of the cut and fill banks, as shown in figure 4. Note that clearing and grubbing areas are horizontal measures, while seeding area is a slope measure.

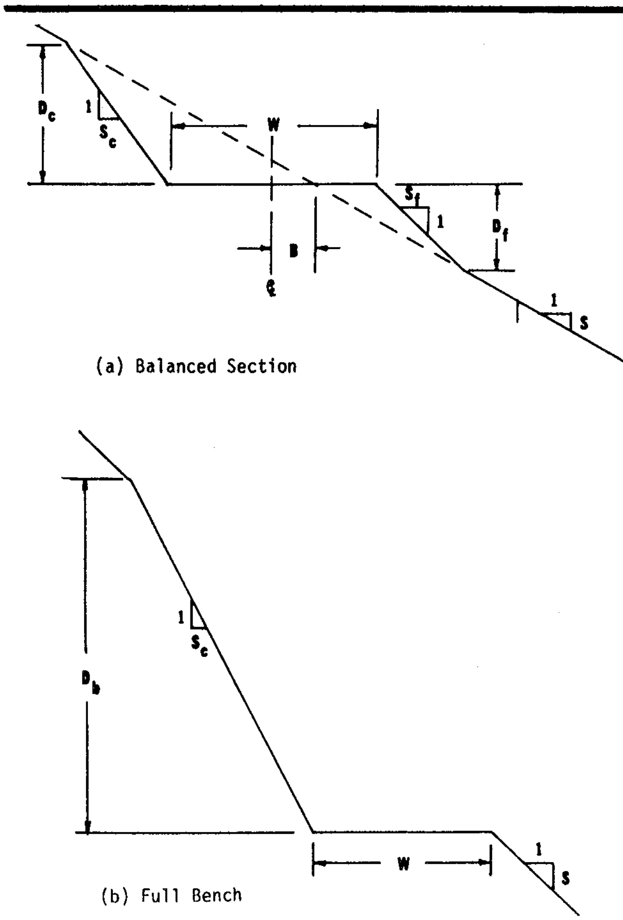


Figure 1.--Excavation volume.

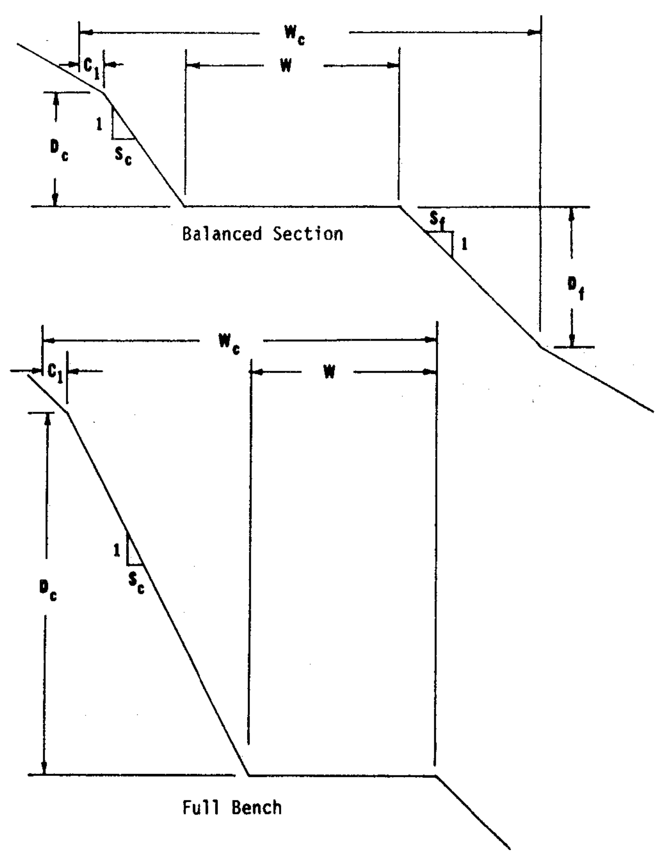


Figure 2.--Clearing area.

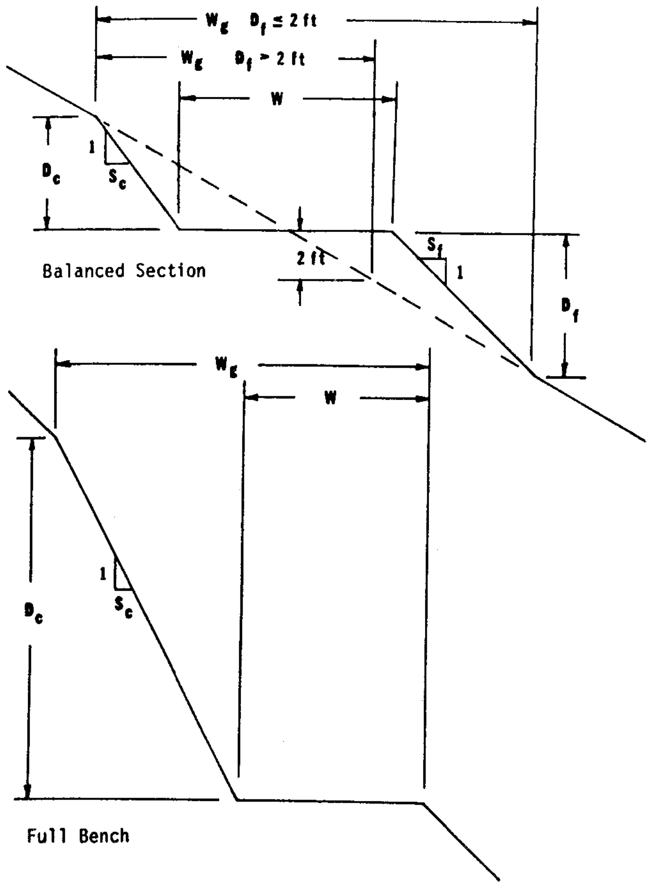


Figure 3.--Grubbing area.

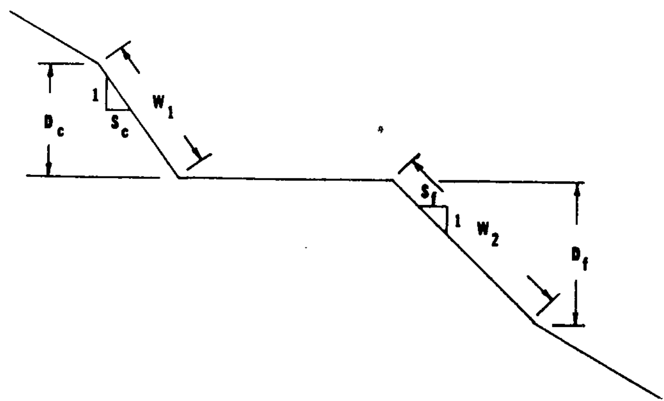


Figure 4.--Seeding area.

The program assumes that ditch relief culverts are installed at given intervals. Culvert length may be estimated for the three different situations shown in figure 5. The first two sketches in the figure show two different approaches for calculating culvert length in balanced section. The culvert length in figure 5a is computed from ditch line to toe of fill where no downdrain is required. The maximum allowable gradient in a culvert is assumed to be 30 percent. If the computed gradient of the culvert exceeds 30 percent, the gradient is assumed to be reduced to 30 percent and a downdrain will be installed. The downdrain length is estimated according to the sketch shown in figure 5b. When a downdrain is required, an additional cost must be added for elbows, anchors, and energy dissipators. Figure 5c shows a sketch of the typical culvert for full bench section.

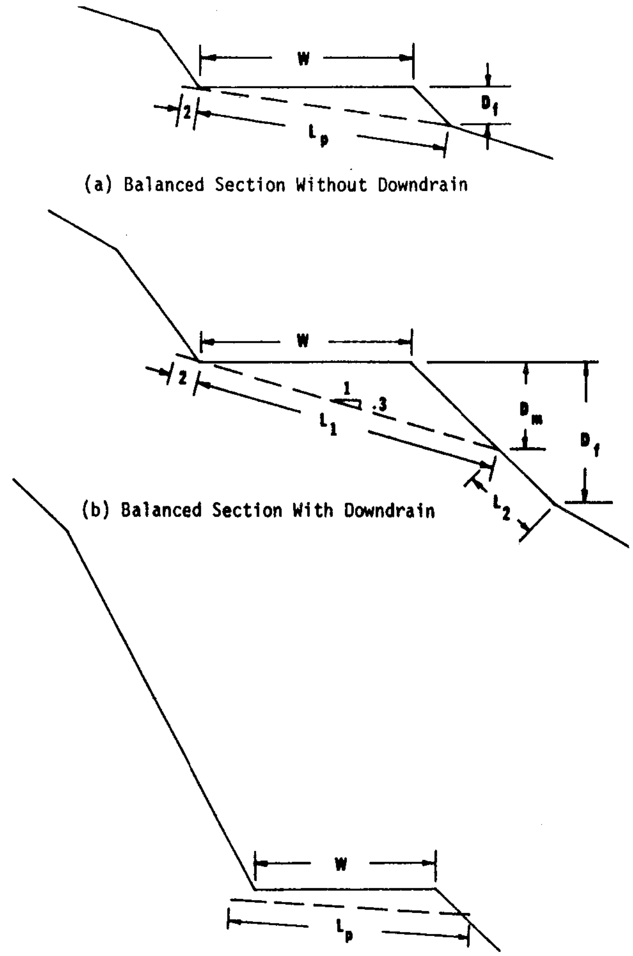


Figure 5.--Ditch relief culverts.

Figure 6 shows the sketch of the typical drainage crossing. It is assumed that additional excavation is required to construct throughfill drainage crossings if the typical section is self-balanced. The additional earthwork is assumed here to be the throughfill volume adjusted for compaction.

The quantity computation equations for excavation, clearing, grubbing, seeding, culvert, and surface were documented in "Simplified Cost-Estimation Method for Low-Volume Roads," Transportation Research Record 898, 1983, by Tom Durston and Fong Ou. The equations were integrated into a computation procedure for developing a program entitled Analytical Road Cost (ARC) for the HP-41C calculator. The program allows the user to specify full bench section or self-balancing section,

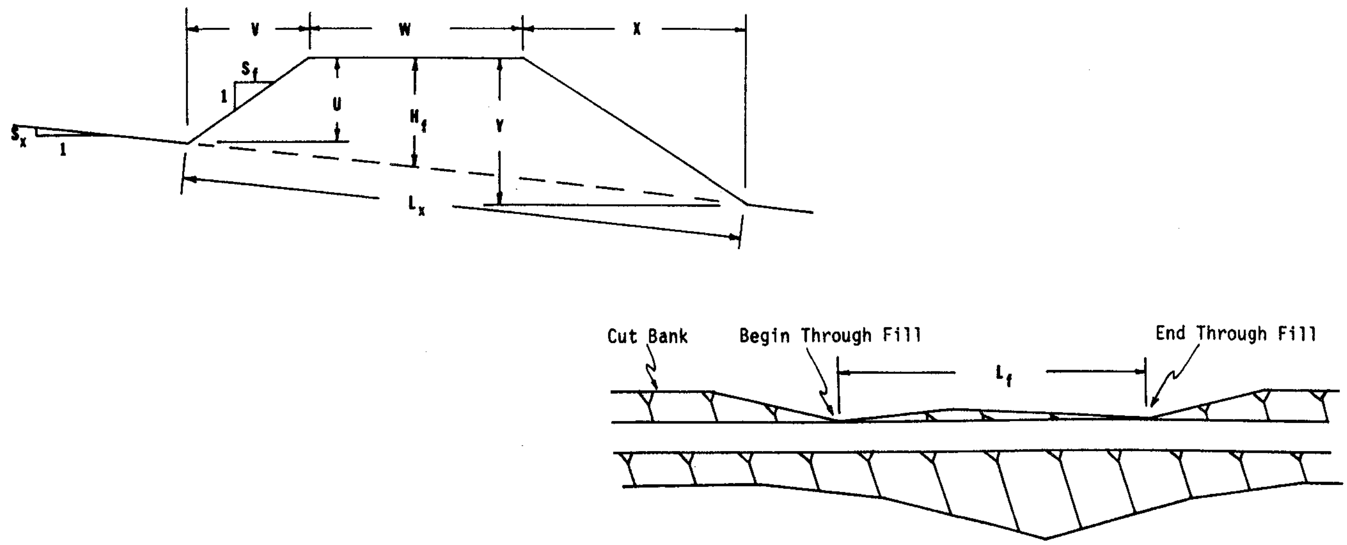


Figure 6.--Drainage crossing.

compaction factor, ground slope, length, earthwork haul distance, rock haul distance, cut slope and fill slope ratios, aggregate depth, distance between culverts, road widths, distance from top of cut to clearing limit, unit costs, and, for throughfill drainage crossings, the length of the throughfill and the depth at the drainage. With this flexibility, the user may test the sensitivity of each factor and formulate various project alternatives. If a project consists of several road segments with different characteristics, the program can accumulate quantities and costs and print the project total. The data used for cost alternatives are shown in table 1.

The PROGRAM

The main program label for analytical road cost is "ARC." The program requires 81 registers allocated to data memory and occupies 221 registers of program memory. Four main subroutines--A, B, C, and D--normally are used by the program user.

(1) Subroutine A begins data entry sequence. If the user wants to start the program over at any point, he may do so by pressing A.

(2) Subroutine B computes the quantities and costs. If the user wants to skip over part of the data entry sequence and use the data already in memory, he may do so at any point by pressing B.

Table 1.--Analytical road cost data.

Road segment ____________________
Side slope (decimal %) ____________________
Length (mi) ____________________
Compaction factor (decimal %) ____________________
Balanced section or full bench ____________________
Unit excavation cost ($/c.y.) ____________________
Haul distance (sta) ____________________
Ditch relief culvert spacing (ft) ____________________
Surface rock haul distance (mi) ____________________
Cut bank ratio (?:1) ____________________
Fill bank ratio (?:1) ____________________
Single-lane subgrade lane (ft) ____________________
Turnout widening (ft) ____________________
Top width in single lane (ft) ____________________
Surface rock depth (in) ____________________
Fraction in single lane (Decimal %) ____________________
Clearing limit distance (ft) ____________________

Unit Costs:
Clearing and disposal ($/ac) ____________________
Grubbing ($/ac) ____________________
Seeding and mulching ($/ac) ____________________
Culvert CMP cost ($/ft) ____________________
Culvert riprap and catch basin cost ($/culvert) ____________________
Downdrain fixed costs, for instance, elbow and anchor ($/culvert)

Haul cost ($/sta.*yard) ____________________
Surface rock production and spreading cost ($/c.y.) ____________________
Surface rock haul cost ($/c.y. * mi) ____________________
Surveying cost ($/mi) ____________________
Mobilization cost (% of total) ____________________

Drainage Crossings:

Length of fill (ft)	_____	_____	_____	_____
Height of fill (ft)	_____	_____	_____	_____
Slope (decimal %)	_____	_____	_____	_____
Unit culvert cost ($/ft)	_____	_____	_____	_____
Riprap cost ($)	_____	_____	_____	_____

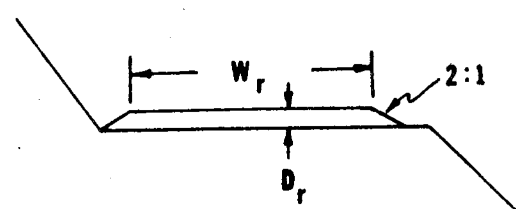


Figure 7.--Surface rock volume.

(3) Subroutine C initializes the project total memories.

(4) Subroutine D prints the costs and quantities accumulated in the project total memories.

Data may be entered in response to alpha-numeric prompts. It is recommended that the printer be used when running ARC.

SYSTEM VALIDATION

The accuracy of the ARC program was checked using four typical roads on the Gifford Pinchot National Forest. The result of each application was compared to a traditional method of estimation and to the Engineer's estimate from the design quantities.

In these four case studies, input data for the road cost estimates were taken from survey and design notes. Slope data were taken from preliminary line (P-line) survey notes. The roads were divided into segments having roughly the same ground slope. These segments were generally 0.3 to 0.5 miles in length. Road design standards and drainage crossing fill heights and lengths were taken from the design. Unit costs from the Engineer's estimates for the four roads were averaged, and the average was used for each ARC estimate. The results indicated that the ARC program yielded estimates that were closer to the "actual costs of" final design than those produced by the conventional method. The estimate errors for the four road segments were -17 percent, +5 percent, -8 percent, and -9 percent for the ARC program, and +1 percent, +69 percent, +59 percent, and +41 percent for the conventional method.

CONCLUSIONS

A quick turnaround cost estimation method has been developed for use in planning Forest roads. The method has been presented in a program written for the HP-41C calculator. Its applicability has been demonstrated in four case studies. The results of these studies indicated that the developed procedure can make accurate and consistent estimates. A transportation planner may use the estimation method to examine various alternatives and identify the most cost-effective Forest road system.

The analytical road cost program and its user's guide are available from the Gifford Pinchot National Forest. Direct questions and comments to Tom Durston at FTS 422-7582 or (206) 696-7582.

Potential for Engineering Cost Savings With Analytical Photogrammetry

Wayne Valentine
Regional Geometronics Group Leader
Region 1

INTRODUCTION

"More with less" is one of the current buzz phrases circulating through our agency. "Cost reduction" is another. Unfortunately, these phrases often mean very little. We often hear these phrases spoken, but distressingly little is actually done to change the way we effect meaningful cost reductions.

There are many reasons why we continue business as usual. One reason is lack of true incentive to change, another is the human tendency of inertia and distrust of anything new, still others are bureaucratic obstacles and failure to recognize, reward, and promote innovation. Another reason concerns our approach to cost reduction. Characteristically, we attempt to shave 5 percent here, 10 percent there. Instead, we need to take a new look at major cost centers to effect quantum savings.

Take the collection of terrain data for timber sales and other engineering purposes, for example. The basic technique employed for this job is the same that was used on the Erie Canal and during the railroad construction days. We are still using centuries-old methods, partly because everyone loves to go to the field to survey. It's fun to get into the great outdoors, eat lunch with the bears, and drag a tape through the brush. Field work is traditional and part of the Forest Service culture. It satisfies the urge to "do something," and it appears wonderfully productive and busy. But field methods are costly. They're slow, inefficient, error-prone, labor-intensive, season and weather-dependent, and often ineffective.

Worse, experience has shown that a high percentage of these costly field surveys never amount to anything. How many miles of surveyed road never have been--and never will be--built? How many sales have been laid out that never will be cut? We'd be embarrassed to find out! The up-front investment of field surveys often has a very low chance of payoff. Another problem concerns the many times that field surveys have to be repeated because of deficiencies in the data. The data are either incomplete or wrong. We often have been accused of over-engineering. We are seldom criticized for engineering-over, yet this problem is actually much worse.

Traditional, old-time field methods of data collection for engineering purposes are costly, inefficient, and often wasted. We should move on to other methods that are more reliable, less costly, and less of a loss if the project never comes to fruition.

RECENT ADVANCES in PHOTOGRAMMETRY

Photogrammetry has been around for years in the Forest Service, but it has never caught on. Our field people do not "think photogrammetry" when faced with a surveying job. The reasons for this are many and varied, having to do with knowledge and understanding deficiencies (both by the photogrammetrist and by the field engineer), failures of past projects, poor response time, lack of management emphasis, knee-jerk habits, and process barriers. We hope to change the climate that contributes to this lack of acceptance, and we are happy to report that recent technological advances have nearly eliminated at least three major obstacles to the use of photogrammetry. Because of these advances, which are described in this article, field personnel should be more willing and able to take frequent advantage of this now very efficient, effective, accurate, fast, reliable, and low-investment method of gathering data for engineering purposes.

The key technological advance has been the analytical plotter, a device that weds the computer to a high-precision photogrammetric measuring system, and that uses mathematically rigorous adjustment methods. This advance has increased accuracy at least six-fold compared with older analogue/polynomial methods and has dramatically increased the utility and speed of the plotter in performing basic measuring tasks (as opposed to merely mapping). Therefore, it has considerably shortened the time needed to gather engineering data and create useful graphic plots. Engineering measurements such as road surveys can be made in less than one day from a single stereo model.

Complete plots and computer files, such as RDS files, of this data are available almost immediately. Imaginary lines surveyed by photogrammetric methods, such as the centerline of a proposed road, must be located on the ground if the project is to be built. This problem has been solved by various means in the past none of which were entirely satisfactory. Another method is now possible with the analytical plotter because it records the photo x and y of points surveyed. This record can be reproduced and plotted on the photograph in the scale and projection of the photograph, thus providing a graphical stereo record of actual ground location for use in the field (see figure 1).

Field control also has been a major obstacle to the use of photogrammetry in the Forest Service. The necessary expertise for this most critical phase of photogrammetric operations generally is not found at the user level; hence the acquisition of reliable control has been expensive, frustrating, and time consuming. However, another advance has nearly eliminated this problem. This advance is the widespread availability of the orthophoto, made from high-altitude photography. The images on orthophotos produced by the U.S. Geological Survey and the Geometronics Service Center are accurately located and provide a source of extensive horizontal control. An even more accurate source is the original high-altitude photography, which has been tied together in large blocks by analytical methods to squeeze out the best fit to the triangulation points in the blocks. This can be used instead of field control for many purposes. We have been able to pass control down to resource scale photography and achieve "fits" of less than 2 feet horizontally and 1 foot vertically. Of course, relative accuracy with the analytical plotter is even better than this. The accuracy of these methods is adequate for the majority of Forest Service engineering requirements. Therefore, the need for field control surveys is practically eliminated, except for special applications requiring the extreme accuracy of cadastral surveying.

Accuracy Tests. Recently, an accuracy test was performed with the cooperation of a local Forest. A block of photography consisting of two strips was flown and controlled solely with orthophoto images. The distance between a number of targets was measured photogrammetrically. The same distances

Figure 1.--Plot of ℄ and X sections in photo perspective.

also were measured in the field using electronic equipment. These distances were compared, with the following results: average accuracy across strips = 1:22,700; average accuracy along strips = 1:3,800. In another test, control passed from high-altitude, small-scale photography down to large-scale resource photography. Using the resource photography, a site map was compiled of an area that contained a number of man-made features. Distances scaled from the map were compared with distances measured in the field between the same features. The test showed that it was not possible to make field measurements to the same precision as the map by using normal field methods! The computed scale uncertainty of several stereo models controlled this way typically has been less than 0.04 percent, and often as low as 0.02 percent.

Internal precision of a typical modern analytical stereo plotter is less than 10 micrometers. This precision figure times the photo scale gives an idea of the relative measurement capability in the stereo model. For example, points on a 1:12,000-scale photo can be pointed to within about 0.4 feet (see figure 2). These results demonstrate the achievable accuracy of photogrammetry, even using crude methods of control. Appropriate accuracy is readily available by photogrammetry, even without considering the philosophy of "barely adequate" engineering.

COST- & TIME-SAVING POTENTIAL

The cost-saving potential revealed by these two tests should be obvious. In each case, end products could have been obtained without expensive field control. In the case of the site map, at least 1 crew-day could have been saved, and in the case of the strip, at least 2 days. Each of these jobs took less than 1 day using the analytical plotter, and results were available immediately. Former methods would have taken several days of plotter time and several weeks before final results could have been obtained.

This fast and accurate measuring capability can be put to use for many terrain data collection needs. For example, it is possible to prepare high-quality topographic maps of timber sale areas using existing materials. These maps can be used for sale planning, road location, cable sets, and cutting areas. Additional engineering measurements can be taken from existing photography for cable logging systems.

High-altitude photography bridged by the USGS for orthophoto production is becoming increasingly available. Pugged diapositives of these photos can be obtained from the U.S. Geological Survey for a slight fee. Positions of common images can be measured on the HAP and used to control larger scale photos. Using this technique, we have been able to control resource scale photos with rmse fits of better than 2 feet horizontally and 1 foot vertically. Scale uncertainty of the resource photography is commonly less than 0.04 percent, (and often as low as 0.02 percent), as determined by the standard deviation of the computed height of camera stations.

With a point-positioning accuracy of 5 micrometers rmse for the analytical plotter, an estimate of the ground distance uncertainty (rmse) between two points in a stero model can be computed as follows:

Dist. uncert., ft., = + ((d*Su)**2 + 2*((0.000005*PSR*3.281)**2))**1/2

d = distance measured
PSR = photo scale reciprocal
Su = photo scale uncertainty

Example:

Photo Scale = 1:24000
Scale Uncertainty = 0.0002
Dist. = 1000 ft
Estimated distance uncertainty = 0.6 ft

Figure 2.--Accuracy of measurements from large-scale photos controlled by images from pugged HAP.

Cable Profiles. Cable profiles that are run in the field typically require at least a two-person crew. A crew produces about two profiles per day, for data collection only. The data then must be reduced and plotted. Using the analytical plotter and high-altitude control, as many as 80 profiles have been measured in 1 day, complete with plots and reduced data. The potential savings using this method instead of the field method are enormous.

Road Surveys. Road surveys to collect terrain information for design and cost estimating are another application with potential for significant savings. The sale area is accurately mapped at large scale--1,000 feet per inch with 20or 40-foot contour interval. Ground features influencing road location also are mapped (slides, bogs, steep terrain, and so forth). The location engineer then carefully plots a proposed alignment on the map. This alignment is converted to bearings and distances by digitizing, and those data are stored in the analytical plotter. The plotter recalls this information and "steers" the measuring mark along this P-line in a large-scale stereo model that is controlled by high-altitude photography. The operator measures the profile and cross sections along the proposed route and stores this data in a form compatible with RDS. In a recent project, three alternate routes totaling approximately 1.5 miles were surveyed by this technique. Cross sections of 500 feet were taken and large-scale strip maps were constructed for final design. The jobs of data collection, reduction, and plotting were completed in less than 5 days. With conventional field methods, it is doubtful whether 2,000 feet of line could be located and surveyed with 500-foot cross sections in 5 days, let alone reduced and plotted.

After the road is designed, the L-line can be converted to photo x and y coordinates and plotted exactly on the photo. This will assist the field personnel in locating the line on the ground (see figure 1).

Surveying existing roads for reconstruction is a snap with photogrammetry. Because the alignment usually is essentially preserved, the plotter operator simply traverses the existing road, cross-sectioning at specified intervals. Daily production rates of from 3 to 5 miles have been achieved on projects of this type.

Site Mapping. For mapping of small areas at large scale, such as recreation areas, bridge sites, electronic sites, and administrative improvements, the analytical plotter with orthophoto or high-altitude photo control will save thousands of dollars and provide designers with excellent quality tools in a short time. A recent project illustrating this capability involved relocating a stretch of very steep, dangerous trail in a wilderness area. The area was mapped at 50 feet per inch with a 5-foot contour interval; trail locators will use this product to do a detailed study of alternate routes. The entire mapping job took less than 3 days in mid-winter!

Close-Range Photogrammetry. The analytical plotter also can be used with photos taken from the ground. This terrestrial or close-range photogrammetry (CRP) has applications in a variety of situations. For example, we abandon and tear down many older guard stations, bunk houses, lookouts, and other buildings. These old structures are a cultural resource; a record of our past. To preserve this record, we prepare architectural drawings of many of these structures. This job, if done by hand, can cost more than $1,000 per building. With stereo photos, the buildings can be plotted by photogrammetry. Two building views can be compiled in less than one day, and a more complete drawing showing all the knot holes, woodpecker nests, cracked beams, and sagging porches is prepared as well. It simply is not possible to prepare as detailed a drawing by hand. Rock faces, bridge inspections, log decks, material stockpiles, and bridge sites can be mapped in a similar way.

CONCLUSION

Analytical photogrammetry is not the ultimate answer to engineering data collection needs. Heavy tree cover (more than 60 percent canopy) obscures the ground and lessens the accuracy with which the terrain can be mapped. Surveyed lines must be put on the ground. However, photogrammetry offers the opportunity to reduce and delay expensive field operations until the project is certain--that is, until the sale is offered for bid or even actually sold. Expensive field operations can be minimized, project time shortened, and data collected in the off-season. The total "at risk" investment in data gathering for engineering purposes can be significantly reduced.

The potential for major savings through the use of photogrammetry has been adequately demonstrated (see figure 3). The source of quality control now available for use in analytical plotters removes major barriers to the use of this technique. The analytical plotter is not just a mapping tool, but an engineering measuring system with speed and accuracy. We urge Engineers in the Forest Service to "think photogrammetry" for field data collection needs.

CABLE PROFILES (840 each - 396 miles)
Ground Methods: 840 x 10 man-hrs x $9 = $75,600
Analytical Method: 12 weeks x $520 = $6,200 SAVING: $69,400

ARCHITECTURAL DRAWINGS (17 views)
Contract Architect: 17 x $750 = $12,700 =
Analytical: 17 days x $100 = $1,700 SAVING: $11,000

ROAD SURVEYS (40 miles)
Ground methods: 100 crew days x $340 = $34,000
Analytical: 40 man days x $100 = $4,000 SAVING: $30,000

SITE SURVEYS (33)
Usual Methods: ((2 crew days x $340) + (3 man days x $100))(33) = $32,300
Analytical: 66 man days x $100 = $6,600 SAVING: $25,700

ROW SURVEYS (20.5 mi.)
Ground methods: ((2 1/3 crew days x $200) + (1.5 man day x $75))(20.5) = $11,800
Analytical: 31 man days x $100 = $3,100 SAVING: $ 8,700

OTHER PROJECTS (Mapping of slides, etc.)
Conventional cost = $5,100
Analytical cost = $300 SAVING: $ 4,800

TOTAL: More than $140,000

This is a conservative estimate. During the time period, much process development and training also occurred, so the plotter did not achieve full production. Nevertheless, this shows that large savings are possible by using these methods to acquire field measurements for engineering purposes. Note also the much smaller investment placed "at risk" in the case of the road and cable surveys. If these projects never develop, a much smaller investment in data gathering is lost.

Figure 3.--Estimate of some of the costs avoided or saved in Region 1 during fiscal year 1985 by using the analytical plotter and other modern photogrammetric methods. Only manpower savings are estimated. Other savings, such as travel, transportation, and administration support, are not included.

Decisions...Decisions...Decisions

Jim Suhr
Management Methods Engineer
Region 4

Making a good decision could be the most important thing you do. This becomes apparent when we examine the results of bad decisions. Examples range from minor inconveniences to the worst possible result--war.

Jim Suhr, sometimes called the father of tradeoff evaluation process (TEP), says the process has needed a new name for quite awhile and now would be a good time to start using one. He believes that "choosing by advantages," or CBA for short, more accurately describes the process. So CBA will be used throughout the following interview. Whether or not it becomes the permanent title will be decided by the users.

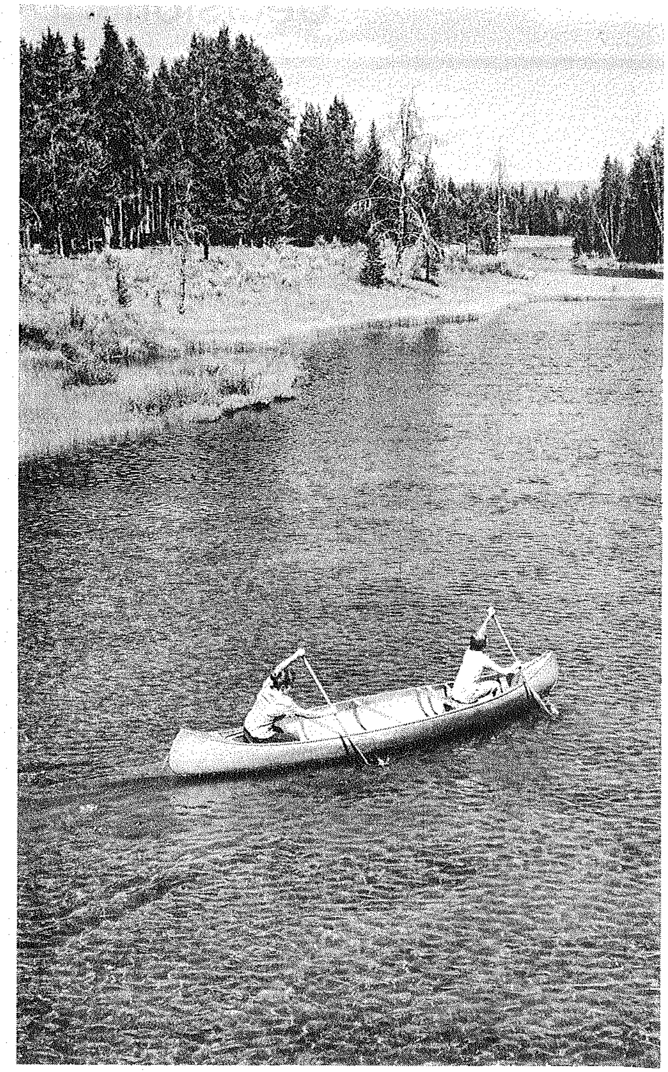
If the process is simple, many people ask, why do we need training sessions to explain it? The answer is that only the situations can become complex--not the process.

We've probably all heard at least one version of the following story: A farmer hired a man to dig post-holes. The fellow quickly completed the job, then came back the next day and cleared stumps in record time. The third day the farmer rewarded him with an easy job--sorting good and bad potatoes. After about three hours the man fainted. Revived, he exclaimed: "Oh the job was easy enough--but those decisions just mowed me down."

If you want to survive your job and avoid making some of the world's worst decisions, read the following interview with Jim Suhr.

HOW TO SIMPLIFY DECISIONMAKING

QUESTION: Jim, for those of us who know very little about TEP--referred to here as choosing by advantages, or CBA--would you give a brief description?



ANSWER: Choosing by advantages is a decision method that simplifies and clarifies the decisionmaking process. It is an excellent method for a wide variety of decisions, from very simple to very complex.

Q: Where is this method being used?

A: It is being implemented primarily in the Forest Service, with the Intermountain Region taking the lead. Several of the Forests in this Region have helped in the development of the CBA method and have used it in Forest planning and other kinds of decisionmaking. It also has been used in other organizations. But one of its best applications is by individuals for personal decisions.

Q: Why was CBA developed in the first place? Why not use the methods that were already available?

A: There were and are dozens of decision methods available. Some of these methods are sound, and they can lead to good decisions. Some are simple. But most of the sound methods are too complex, while the simple ones are unsound. Worst of all, many are both unsound and complex.

Choosing by advantages is sound, clear, and simple. So it substantially improves the decisionmaking process. Designed to meet the needs of decision-makers--you and I, for example--it answers three vital questions:

(1) How can I make sound decisions?

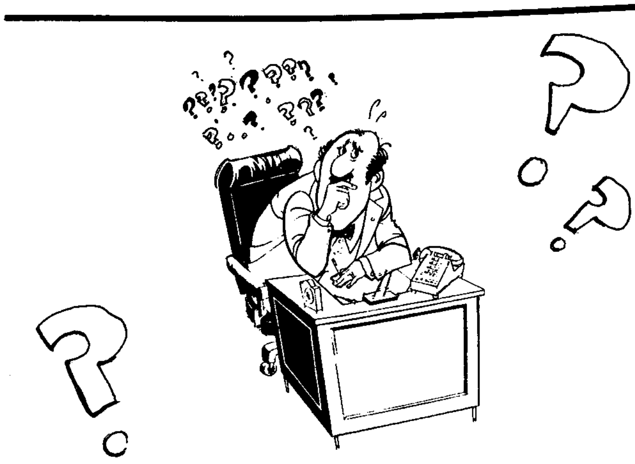
(2) How can I show clearly that my decisions are sound?

(3) How can I simplify decisionmaking?

Q: What is different about choosing by advantages, compared with other methods?

A: It differs, most of all, in the one area that really matters--in the way decisions are made. It is the only decision method that applies the fundamental rule of decisionmaking: decisions should be based on the importance of advantages.

This decision rule tells the whole story. It summarizes the method. To decide, just choose the alternative with the most important set of advantages.



Q: What about disadvantages? Shouldn't they be taken into account?

A: Yes, disadvantages must be taken into account. But an advantage of one alternative is a disadvantage of another. Therefore, disadvantages are automatically taken into account when we base decisions on the importance of advantages.

Q: Could you give an example of how disadvantages are taken into account?

A: Let's start with a specific definition of "advantage." This definition is a key to understanding how to make good decisions. In this context, an advantage is defined as:

> A Favorable Dissimilarity, or a Favorable Difference Between Two Alternatives

To illustrate this definition, let's buy a new canoe.

Suppose we have narrowed the choice to only two options, canoe C and canoe K. These two options are the same in every way except in one factor--color. They have the same weight, the same dimensions, and the same durability. And because they have the same price, the choice between C and K is a nonbudget decision.

In this example, everyone who is involved in the decision prefers the color of C. Therefore, option C has the color advantage. Option K has no advantages. Obviously, we should choose C.

While the dissimilarity in color is an advantage of C, this same dissimilarity is a disadvantage of K. We must count, but not double count, this dissimilarity. We can count it as an advantage, which is positive, or as a disadvantage, which is negative, but not both. Choosing by advantages is the positive approach. And for this reason it leads to effective decisions--sound decisions that are likely to be accepted and implemented.

Q: To what extent is the CBA process being used by individuals for personal decisionmaking?

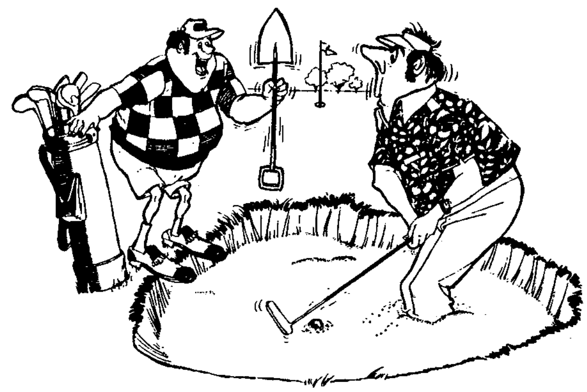
LIST ADVANTAGES ONLY

A: Its use in personal decisionmaking is just beginning. But there are plenty of success stories already. Here is an example. A middle-aged man with serious difficulties in his life said that before learning how to use this method he saw all possibilities in his future as negative. He saw mostly disadvantages in every option. As a result, things weren't going well for him. After learning the CBA method, he said he was able to turn his life around. For the first time in years he could see that his future could be positive. With a better vision of the future, he was able to improve his life.

In the past, psychologists have often told their clients to list the advantages and disadvantages of each option in their future and to choose the best option. But research has shown that people tend to magnify the importance of differences among alternatives when they are listed as disadvantages. That tendency, plus the double counting that occurs when both advantages and disadvantages are weighed, often leads to bad decisions. Psychologists and others who give advice should tell their clients to list advantages only.

Q: Is the method the same for complex decisions?

A: The same fundamental decision rule applies in all kinds of decisions, from the most simple to the most complex. That is, decisions should be based on the importance of advantages. But for complex decisions, the process must be divided into bite-sized steps. The entire process has three major phases:



(1) Stage-setting activities.

(2) Decisionmaking activities.

(3) Implementation activities.

Stage-setting includes formulating alternatives and collecting data to determine the attributes, or characteristics, of each alternative. And it may include other activities, such as identifying problems and their causes.

For complex decisions, the second phase, decision-making, is also divided into several activities. And for very complex decisions, these activities are further divided into simple tasks. But it takes nearly 2 hours to explain these tasks, so I think we should not try to do it here. Come to a training session to learn these tasks if you plan to use the CBA method for complex decisions.

Q: Can we learn to use the method of choosing by advantages for simple decisions without going to a training session?

A: Certainly. All you need is two or three examples to follow. And you have one example already--the choice between canoes C and K.

The key to following the examples will be to avoid complicating and confusing the method. For example, do not include inappropriate activities from other methods. It takes a lot of time in the training sessions to discuss this issue. It takes time to demonstrate, for example, that weighing both advantages and disadvantages is an unsound method.

It is confusing, and it often causes bad decisions. Keep decisionmaking sound and simple by weighing advantages only--no disadvantages. In fact, I think we would be better off if we eliminated the term "disadvantage" from our vocabularies.

EXAMPLES of CHOOSING by ADVANTAGES

Q: Could you give one or two examples that are a little more complex than the canoe example?

A: All we need to do is to expand the canoe example by comparing canoes A and B, rather than C and K. This also will be a simple nonbudget decision, with only two alternatives. But it will have three advantages, rather than only one. Here are the decisionmaking activities for this kind of decision:

(1) List the advantages of each alternative.

(2) Choose the alternative with the most important set of advantages.

The first activity, listing the advantages, requires only two tasks. First, decide the least preferred attribute in each factor. For example, if canoe A weighs 68 pounds, while canoe B weighs 61 pounds, the 68-pound weight of A is the least preferred attribute. Second, determine the difference from the least preferred. This difference of 7 pounds (68-61) is an advantage of B. The advantages of each alternative are listed below:

Advantages of Canoe A	Advantages of Canoe B
Better color than B Slightly sturdier than B	7 pounds lighter than A (68-61)

In this example, the decisionmaker chose canoe B. For him, the one advantage of B outweighs the two advantages of A. But a very strong, heavy decisionmaker would choose A. For the first decisionmaker, option B would be the best choice. But for the second, option A would be the best.

Now, let's increase the complexity of the example. Let's choose between canoes X and Y. In this decision, a larger number of advantages must be considered--too many to be clearly perceived at one time. But the decision, again, is a nonbudget decision, with only two alternatives. Here are the decisionmaking activities for this kind of decision:

(1) List the advantages of each alternative.

(2) Decide the importance of each advantage.

(3) Choose the alternative with the most important set of advantages.

When this variation of the method is used, there is no limit to the number of advantages that can be taken into account.

In the second activity, deciding the importance of advantages, a numerical scale is used. Scales of 0 to 1, 0 to 10, or 0 to 100 are the most useful. Following is the comparison of canoes X and Y, using a 0-to-100 scale.

Importance of Advantages

Advantages of Canoe X		Advantages of Canoe Y	
Better color	45	7 pounds lighter (68-61)	100
Slightly sturdier	5	Better flotation chambers	40
Better seats	10		
Total Importance:	60	Total Importance:	140

In this example, the decisionmaker or decisionmakers chose option Y. This was a sound decision because it meets two basic requirements:

(1) It is based on the relevant facts.

(2) It is based on an appropriate view point.

Q: How can you decide whose viewpoint is the appropriate viewpoint?

A: My bias is that those who are most affected by the decision should have the most influence in the decisionmaking process. For example, many day-to-day decisions are by you and for you. For those decisions, I believe you are the one whose viewpoint is the appropriate viewpoint. Not everyone agrees with my bias, of course.

You can use the three canoe-selection examples as models for a lot of your day-to-day decisionmaking. For example, choosing by advantages is an ideal method for decision meetings. For simple decisions, the group involved should just list the advantages of each alternative. Then, if necessary, decide the importance of each advantage individually. (For simple decisions, this second activity is unnecessary.) And finally, choose the most important set of advantages.

Of course, many of the decisions we face are more complex than the three examples of choosing from pairs of canoes. Often, three or more alternatives--sometimes a very large number--may need to be considered. And budget advantages are often involved. If so, the method has to be changed slightly because the sound methods for nonbudget decisions are unsound for budget decisions. Money amounts must be included in the process as constraints, rather than including money differences as advantages.

Additional complications may include the need to compare short-range and long-range advantages, and the need to take uncertainties into account. Nevertheless, for all types of decisions, the process of choosing by advantages has the same three central decisionmaking activities:

(1) Decide the advantages of each alternative.

(2) Decide the importance of each advantage.

(3) Choose the preferred alternative.

Q: Thanks for sharing this new decision method, Jim. It can help us improve our decisions and our lives.

How To Make Sound Decisions

Choosing by advantages corrects a major defect that exists in most of the widely used decision methods. This defect has caused many faulty, unsound decisions. It is the critical mistake of judging the importance of criteria, factors, objectives, goals, or other generalities.

Suppose, for example, you must choose between two bridge design options, A and B. You know that:

- A is better than B in safety.
- B is preferred to A in esthetics.
- There are no other differences between the two alternatives.

But you don't yet know the magnitude of the differences in safety and esthetics. In the choosing by advantages process (CBA), you would first determine these differences--the advantages of the alternatives. Then, you would ask yourself, "Which ADVANTAGE is the most important."

In several of the popular methods of decisionmaking, first you would ask yourself, "Which FACTOR--safety or esthetics--is the most important." And this is not a good question. It leads to this illogical thought: "Safety is more important than esthetics, so I should choose option A." In fact, the difference in safety may be very small and unimportant compared with the difference in esthetics. If so, you should choose option B.

Remember, do not weigh factors, criteria, or any other generalities. Do not weigh attributes or rank the alternatives as they relate to criteria, objectives, or factors. All of these methods, and many others, lead to unsound decisions. Do weigh the advantages. Then choose the alternative with the most important advantages. This is the key to sound decisionmaking.

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Article courtesy INTERMOUNTAIN REPORTER

Network Analysis Using Microcomputers for Transportation Planning

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WASHINGTON OFFICE NOTE

The following paper[1] by John Sessions describes software that he has developed for network analysis using HP 9020 and IBM-PC. The development was funded by Region 10 and therefore is available to other Regions. Regional Transportation Planners have seen the system demonstrated and should be contacted first if the reader has questions.

INTRODUCTION

Until recently, only large computers could use a combination of network algorithms and mathematical programming to analyze multiple period, fixed, and variable cost networks. Examples of programs include the timber transport model, TIMBRI (Sullivan, 1974), and TRANSHIP (Kirby, Wong, and Hager, 1981). The use of microcomputers for network analysis has been possible, but for only simpler problems. Dykstra and Carson (1978) implemented a modified Moore algorithm (Martin, 1963) to find the shortest path for a truck haul through a network, from the point of entry to a predefined destination. The shortest path could be expressed as minimum cost, distance, or time. However, the algorithm is limited when applied to the broader problem of determining a combination of optimal routes, specifically when considering:

(1) Alternative logging systems.

(2) Alternative destinations.

(3) Multiple products.

(4) Alternative road locations.

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[1]This paper was published in the Proceedings of the Sixth Pacific Northwest Skyline Logging Symposium, Vancouver, British Columbia, May 8-11, 1985.

(5) Alternative road standards.

(6) Multiple time periods.

(7) Maximizing values.

Consequently, a new microcomputer program, NETWORK, was developed. NETWORK is available in HP-BASIC for the HP 9020 and in Microsoft BASIC for the IBM-PC. Initial testing of the program indicates quick proficiency by personnel unfamiliar with microcomputers and network analysis. The network solution procedure begins by preparing a simple map using links to represent, for example, alternative logging systems, road locations, road standards, pipelines, railroads, or barge routes. These links join nodes that typically represent logs in the field, landings, sort yards, or mills. Input consists of entering two lists of information: one list is of existing, proposed, or alternative links; the other list is of origins where material will enter the network and of destinations where the material will leave the network, along with the volume the activity will generate and the year in which the activity will occur. The solution identifies the combination of routes that will be used to provide the minimum total cost or maximum value.

Optimally, NETWORK can solve problems involving only variable costs and values. It uses a set of rules, known as a heuristic, to assist in analyzing cases involving fixed and variable costs. Limited experience has indicated that the solutions provided by the heuristic are feasible and usually quite good. Sensitivity analysis then can be used to test for superior solutions.

NETWORK's problem capacity with 360K accessible memory is approximately 1,000 links, 500 nodes, and 500 harvest areas (origins). Execution time is machine and problem dependent.

MODELING TRANSPORTATION

Network analysis techniques are useful for identifying the minimum cost, time, or distance needed in moving from one point to another in a network. A system of Forest roads, including truck roads, skid trails, and yarding corridors, may be thought of as a network. The nodes may represent wood at the stump, landings, mills, points where road design standards change, grade breaks, bridges, or road intersections.

Imagine that a forest owner has several timber stands scheduled for harvest during one or more time periods, and each stand will produce several different products (peelers, sawlogs, pulpwood). Additionally, consider that some parts of the road network should be rebuilt before the products are hauled to one of several mills that pay different prices for each product. The question facing the decisionmaker is: Which products should be hauled to which mills to maximize discounted net revenue?

The decision requires consideration of route alternatives, construction alternatives, associated maintenance and haul costs, and the different mill prices.

The key to using network analysis for modeling logging transportation problems is the construction of an appropriate network. Quite literally, if you can draw the appropriate network, you can solve the problem. Common network components are discussed below.

Proposed Roads. A proposed road link is described by its beginning and ending nodes, haul cost, and construction cost. Maintenance is discussed later. The haul cost for the link is the roundtrip cost for hauling with a loaded truck in the direction of the ending node. This definition assumes the unloaded truck will return along the same path. If the loaded truck could go in either direction along the link, a separate link must be identified with the appropriate beginning and ending nodes, and maintenance and construction costs. Figure 1 shows a road network with three landing nodes and a mill node. The haul cost for

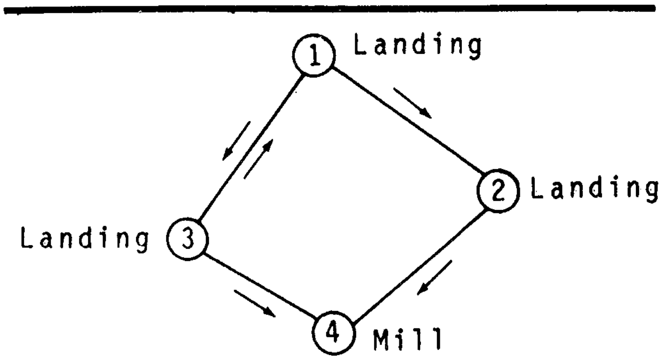

Figure 1.--Road network showing possible haul directions.

transporting each board foot, ton, or unit is the variable cost for the link. The term "variable" is used because the total cost for transporting a given volume will vary directly with the volume hauled. The fixed cost for the link is the construction cost.

Existing Roads. Existing roads are modeled in the same way as proposed roads, except that the fixed cost is now any necessary reconstruction cost. If no reconstruction is necessary, the fixed cost for the link is zero.

Road Maintenance. Road maintenance costs may be of two types, variable or fixed. Variable maintenance costs, such as surface rock replacement, often may be represented as a cost that is proportional to the volume transported and can be added to the haul cost as a variable cost. However, costs such as ditch and culvert cleanout may not be proportional to the volume hauled. In this case, the sum of discounted ditch and culvert maintenance costs would be added to the construction or reconstruction cost as if the link would be added to the system in year zero. If the link is not needed until a future year, the entire fixed cost for the link is discounted to the first year of use.

Logging Systems. Logging systems are one-way links with a beginning node at the stump and an ending node at the landing. A logging link can represent a skyline corridor; a skyline, tractor, or helicopter unit; or a group of adjacent units using weighted costs and accumulated volume.

The landing usually is also the beginning node of one or more road links, as shown in figure 2, but

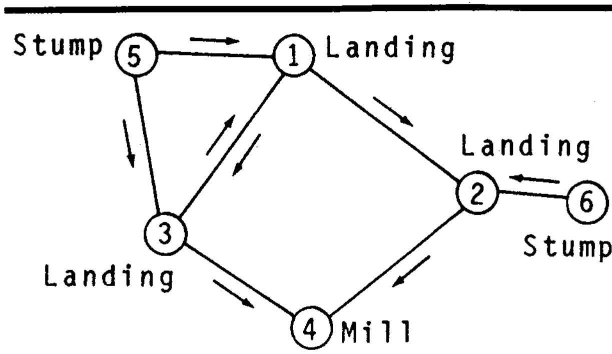

Figure 2.--Network with road and logging system links.

it could also be a swing landing. The variable cost is the felling, yarding, loading, or other cost component that is proportional to volume transported over the link. The fixed cost might include move-in, rig-up, or be zero. The logging variable-cost units must be the same as for the road variable-cost units--for example, dollars per ton, dollars per unit, or dollars per board foot. The fixed costs are only in dollars per link.

Multiple Road Standards or Locations. The least-cost road standard or location requires a tradeoff between construction and haul costs. Because the haul volumes over a link are determined during problem solution, a choice of road standards cannot be made before the haul routes are determined. Instead, each road standard is considered a separate link and is included in the network. During problem solution, the choice of the road standard and haul route will be made simultaneously. Because two links cannot have the same beginning and ending nodes, an additional node and dummy link must be added for each standard, as shown in figure 3. Alternative road locations between two points can be handled the same way.

Multiple Destination. To specify a management action, the origin node, where the wood enters the transportation system, and the destination node, where the wood leaves the transportation system, must be specified. Often, there is more than one possible destination, and if there is no capacity restriction, the analyst must identify which destination results in the least road and transport cost. This can be done in the following way. As shown in figure 4, all potential destinations that

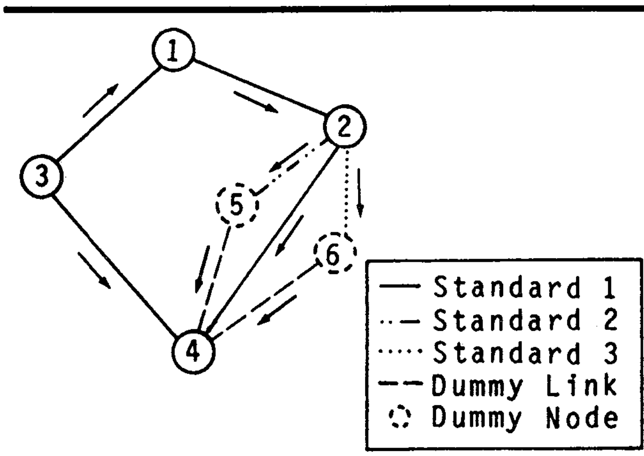

Figure 3.--Network with alternative road standards.

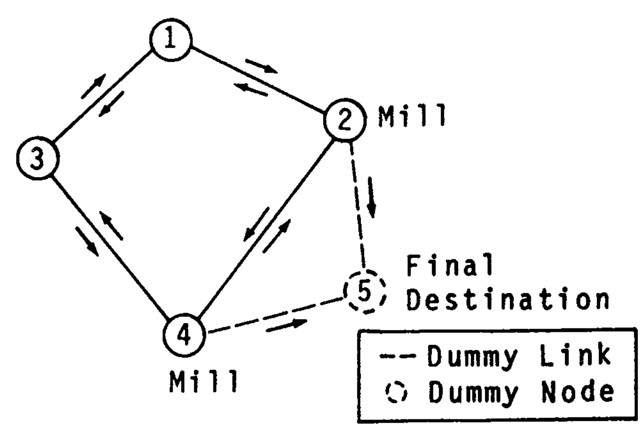

Figure 4.--Network with two possible mill destinations.

can receive the same product are connected by one-way dummy links to a new dummy node, which acts as the final destination. In this way, all wood destined to become the same product arrives at the final (dummy) destination. To identify the actual destination node, it is only necessary to check the second-to-last node of the optimal path from the harvest area to the dummy destination.

Multiple Products. When a timber stand may produce more than one product, each product is represented by a separate harvest area; thus, multiple nodes (harvest areas) replace the single harvest area, as shown in figure 5. Alternative destinations for each product require a separate dummy destination for that product.

Maximizing Net Revenue. Network analysis techniques originally were derived to find the shortest path where all links were represented by distances; thus, all values were positive or zero. Because the algorithm minimizes costs that are considered positive, revenues are entered as negative costs; therefore, maximizing revenues becomes the same as minimizing costs. To represent gross revenue at the mill, an extra link would be added to the network; this link would have a negative variable cost equal to the revenue and a zero fixed cost.

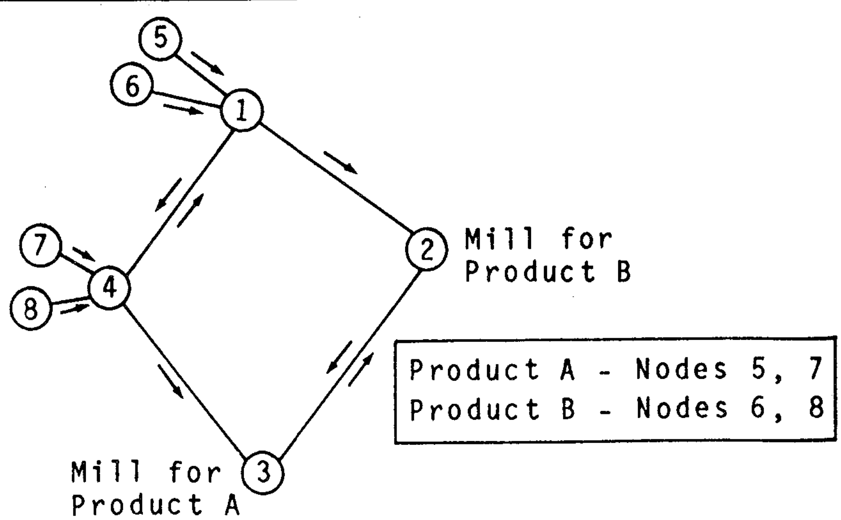

Figure 5.--Network with multiple products.

Other Link Definitions. Other links, such as transfer yards, log dumps, raft transport, and rail transport, can be added to the transportation system by appropriately defining the variable and fixed costs. Definitions for origins and destinations are arbitrary. For example, a rock pit development plan might be modeled using the alternative pit locations and proposed road projects as nodes. Either the pit or the road projects could be considered origins. The costs for the final link to a pit might include a variable cost, such as processing costs in the pit; the fixed cost might be the pit development cost.

Multiple Time Periods. Multiple time period analysis is permitted in NETWORK. No special link modifications are required. The year of the timber harvest is specified. If multiple periods are involved, all results are shown as discounted costs (values) to the present. The model currently does not permit changes in cost or price levels over time. If the same area is to be harvested in several time periods, each harvest is represented by a separate node.

ALGORITHM DESCRIPTION

NETWORK calculates the minimum cost or maximum value network by using a shortest path algorithm to solve the variable cost problem proposed by Ford (1956) and is implemented using the method outlined by Smith (1982). The first iteration minimizes variable costs and ignores fixed costs. Fixed costs are introduced into the variable cost problem by redefining the haul costs at the end of each iteration. This redefinition converts the fixed costs into equivalent variable costs similar to a method discussed by Wong (1981).

Although many shortest path algorithms exist, the one used in NETWORK must have two properties. First, to permit interaction between harvest areas during the solution procedure, the paths must be calculated sequentially. Simultaneous calculations, such as done by Floyd (1962) or in some variants of Moore's algorithm (Dykstra and Carson, 1978), do not allow the required nodal interaction. Second, to permit the maximization of net revenue, the algorithm must accept positive and negative values; therefore, Ford's algorithm was selected for NETWORK. Negative numbers are acceptable as long as there are no net negative circuits within the network. The structure of networks for logging planning normally does not present this problem.

Analyzing multiple time periods is accomplished by beginning each iteration with harvests in the closest time period and progressing to harvests in future time periods. The shortest path procedure is repeated until two consecutive iterations have the same total value.

Results for network planning problems that involve only variable costs will be optimal. Cost (value) will be minimized (maximized) at the end of the first iteration. For networks having variable and fixed costs, the heuristic rules do not guarantee an optimal solution, but the solution will be feasible. When in doubt, suspicious links in the final network should be eliminated and the analysis repeated to force a different solution that can be compared to the original. Also, the solution procedure does not necessarily improve the value of the objective at each iteration, such as in linear programming. In fact, although it is not common, a superior solution may be found in an earlier iteration; therefore, intermediate solutions should be reviewed.

Extensions of the algorithm permit the modeling of more advanced applications, such as using nonlinear haul cost functions to permit tradeoffs between road standards and traffic volume, modeling stage construction, or relaxing the requirement that the unloaded truck use the same path to return to the harvest area as the loaded truck used to the mill.

Although this paper is limited to transportation planning, the algorithm also can be used in project scheduling. By assigning negative variable costs to project activities and zero fixed costs, the minimum project duration and the events on the critical path can be identified. The solution is optimal after the first iteration.

The input and results from a single period network, presented in figure 6, modified from Wong (1981) are shown in tables 1, 2, and 3. In addition to 13 possible construction projects, a road improvement project for link 4-6 also will be automatically considered as link 4-11 and dummy link 11-6. The data in Tables 1 and 2 are the only data to be entered and could be entered directly from a network map. The minimum total cost is $507,058.

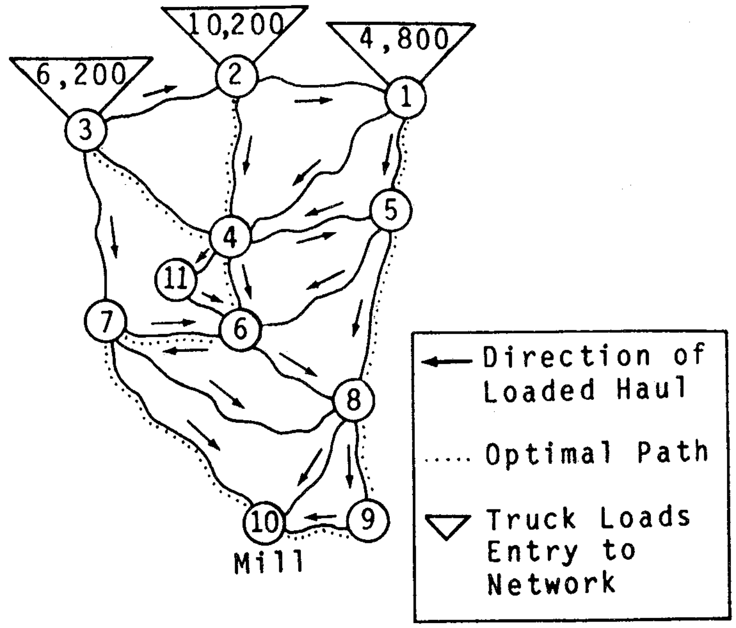

Figure 6.--Example of a single period network.

CONCLUSION

A technique for rapid formulation of logging planning as a network problem has been discussed. A program for microcomputers, NETWORK, has been developed.

There are several advantages of this method for formulating and solving a transportation problem. First, it is easy for both field personnel and analysts to understand it. Second, it can be learned quickly. Third, it requires minimum data input. Fourth, it has interactive capability.

However, there also are disadvantages to NETWORK. One is that the solutions to fixed and variable cost problems may not be optimal, although they are feasible and computationally correct. Sensitivity analyses are required. Another disadvantage is that the scope of the problem is limited to transportation analysis; it does not simultaneously consider tradeoffs between resource activities, such as is permitted in TRANSHIP. And finally, NETWORK does not permit links with capacity restrictions.

Table 1.--Network input for example.

Link Identifier (From)	Link Identifier (To)	Round Trip Haul Cost ($/Truck/Link)	Construction Cost ($/Link)
1	4	10.74	68,400
1	5	3.46	61,300
2	1	6.16	38,200
2	4	3.28	50,000
3	2	5.50	27,800
3	4	3.73	32,500
3	7	3.48	72,700
4	5	4.55	50,000
4	6	3.16	0
4	11	2.50	20,000
5	4	4.55	50,000
5	6	1.42	32,500
5	8	3.16	0
6	7	2.28	50,000
6	8	3.62	28,000
7	6	1.28	50,000
7	8	3.36	0
7	10	5.97	0
8	9	2.70	0
8	10	11.56	0
9	10	5.17	0
11	6	0.00	0

Table 2.--Harvest input for example (single period).

Harvest Node	Destination Node	Harvest Volume (Truck Loads)	Year
3	10	6,200	0
2	10	10,200	0
1	10	4,800	0

Table 3.--Volume summary by link for solution of example.

Link Identifier From	Link Identifier To	Accumulated Volume Over Link (Truck Trips)
1	5	4,800
2	4	10,200
3	4	6,200
4	6	16,400
5	8	4,800
6	7	16,400
7	10	16,400
8	9	4,800
9	10	4,800

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Study of Quality of Aerial Photography

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ABSTRACT

This article is part of an effort to improve the use of photography in the Forest Service. It discusses our work to date on two topics:

(1) Evaluation of procedures used by the Forest Service and the Agricultural Stabilization and Conservation Service-Aerial Photography Field Office (ASCS-APFO) in the acquisition of conventional photography.

(2) Evaluation of the resolution of currently used photographic materials (9-inch by 9-inch format film and paper products).

One of the recommendations in this study is to improve communication between photography users and ASCS-APFO. The photo quality questionnaire is intended to obtain feedback from photography users and to propose corrective actions, if needed. The questionnaire is included with each photography shipment from ASCS-APFO.

The evaluation of resolution may serve as reference material, and it provides several interesting observations on currently used films and other photographic materials. Please note that this study is limited to the use of conventional photography.

INTRODUCTION

Most conventional aerial photography used in the Forest Service is acquired through the Agricultural Stabilization and Conservation Service-Aerial Photography Field Office in Salt Lake City, Utah. The APFO has the responsibility for procurement and printing of all USDA photography covering areas greater than 100 square miles.

ASCS contracts photography acquisition to a number of private firms located throughout the United States. ASCS tailors contract specifications to the requirements of each Forest or Forest section. ASCS inspects the original film flown by the contractor and proof prints according to the Aerial Photography Specifications section within each contract. Rejected photography is reflown, usually during the next flying season, resulting in multiyear coverage.

Each National Forest is photographed on a cyclic schedule at intervals ranging from 5 to 10 years. This results in large volumes of aerial photography that go from the contractors to ASCS, and in turn to users in the Forest Service. During periodic field evaluations of Engineering and Timber Management activities, some photography users expressed concerns about resource photography's quality, scale, or timeliness. (The scale of photography needed to satisfy Forest requirements was addressed in the "Utility Guide for Aerial Photography.")

At the request of the Regions, Washington Office Engineering is conducting a study directed at assessing the quality and timeliness of resource photography. These activities were performed in cooperation with ASCS-APFO personnel. Contract support for part of this study was provided by Attaya Associates, Incorporated.

EVALUATION of PROCEDURES USED by the FOREST SERVICE & ASCS-APFO

Review of Previous Comments on Photography

Washington Office Engineering personnel received comments about photography from Engineering and Timber Management activity reviews in different Regions over the past 3 years. The concerns brought up most often related to multiyear coverage, improper scale, and quality problems. Geometronics personnel and photography coordinators were contacted for more information in those problem areas. As a result of the time elapsed from the time of original inquiry, we were not able to determine the extent of quality problems. Problems are difficult to identify and trace because frequent personnel changes occur at the Forest level, and a single contact for photography often is lacking.

The Forest Service Manual specifies that aerial photography acquisitions for areas greater than 100 square miles must be coordinated through Regional Geometronics Staff and submitted to ASCS for approval and contracting.

Contracting. Requests for new photography are submitted at least 6 months prior to planned acquisition. This gives ASCS sufficient time for flight planning, contract solicitation, and negotiation.

ASCS monitors the progress of each contract and reports periodically to the Forest Service. This study reviewed ASCS contract specifications for Forest Service photography acquisition and U.S. Geological Survey specifica- tions for National High Altitude Photography, and suggested modifications.

Inspection. Once photo acquisition is complete, the contractor delivers the original film along with an index map and proof paper prints to ASCS for inspection. The Forest Service should participate in the inspection process whenever possible. This is especially important if problems in acquisition or film processing yield less than optimum products. The decision to accept inferior photography or to wait until the next flying season should be made very carefully. Several groups use photography with different objectives at each Forest. Prints that are acceptable for one group may not be for someone else. Accepting inferior photography because of time constraints usually causes problems later. Once photography is accepted, the original problems cannot be corrected. Special efforts may be taken in the printing process to improve print quality; however, this takes extra time and can be expensive.

Printing. Original sets of prints may be supplied by ASCS or the contractor (depending on the requesting unit). Subsequent orders (reprints) are provided by ASCS. Color balance may be adjusted during the printing process depending on the quality of the originals and the intended use of the prints or transparencies. If the Forest has a special need, specific instructions and preferred samples to match may be sent with an order. ASCS keeps a file of prints arranged by Forest or Experiment Station that a given unit considers optimal for its use. Using this system, a Forest can receive similar color balance when ordering reprints.

EVALUATION of RESOLUTION of CURRENTLY USED FILMS

The three most common film emulsions used by the Forest Service are color, color infrared (IR), and black-and-white IR. Color negative film is the most widely used, resulting in 9-inch by 9-inch format color paper prints.

Photo quality discussions often include the spatial resolution that can be achieved with a certain film/camera combination. The frequent association of "poor" quality with "low" resolution is not correct. To provide some empirical data, we designed a simple test of the three film emulsions with the same camera using resolution targets. The objectives were to provide a reference set of photography with measured resolution and to compare resolution of the three emulsions.

The photography was acquired over a 2- by 1-mile test site on the Allegheny National Forest, Region 9, on September 7, 1984. A calibrated Wild RC 10 camera was used with a 6-inch lens. Coverage was obtained from six altitudes resulting in the following scales: 1:6,000; 1:8,000; 1:12,000; 1:16,000; 1:24,000; and 1:40,000.

Measuring Resolution

In the following discussions, resolution values are given in terms of Ground Resolved Distance (GRD) in inches. This value is defined as the distance on the ground across a bar-and-space in the element of the test pattern that is just resolved in the image. Smaller GRD values imply that smaller detail can be discerned; therefore, the smaller the GRD, the better the resolution, all other things being equal. However, it is very important to note that GRD values are highly dependent on both the contrast and the particular shape of the resolution test patterns. The three-bar test patterns are fundamentally different in character from normally occurring scene objects. Complicated empirical relationships exist between GRD values and the ability to discern particular scene objects, and these relationships are controversial and generally imprecise.

In this test, a single target layout was contained in each frame (see figure 1). In every case, the target layout contained two targets: one with its bars oriented along the line of flight and the other with its bars across the line of flight. The two target images in each frame were read by three imagery analysts and the three readings were averaged. Then the values for the two targets were averaged to give a single net resolution value for each frame.

Two frames were obtained for each photo scale, and their net resolution values were averaged to give a single overall value for each scale. These resolution data are tabulated and plotted in the accompanying tables and figures.

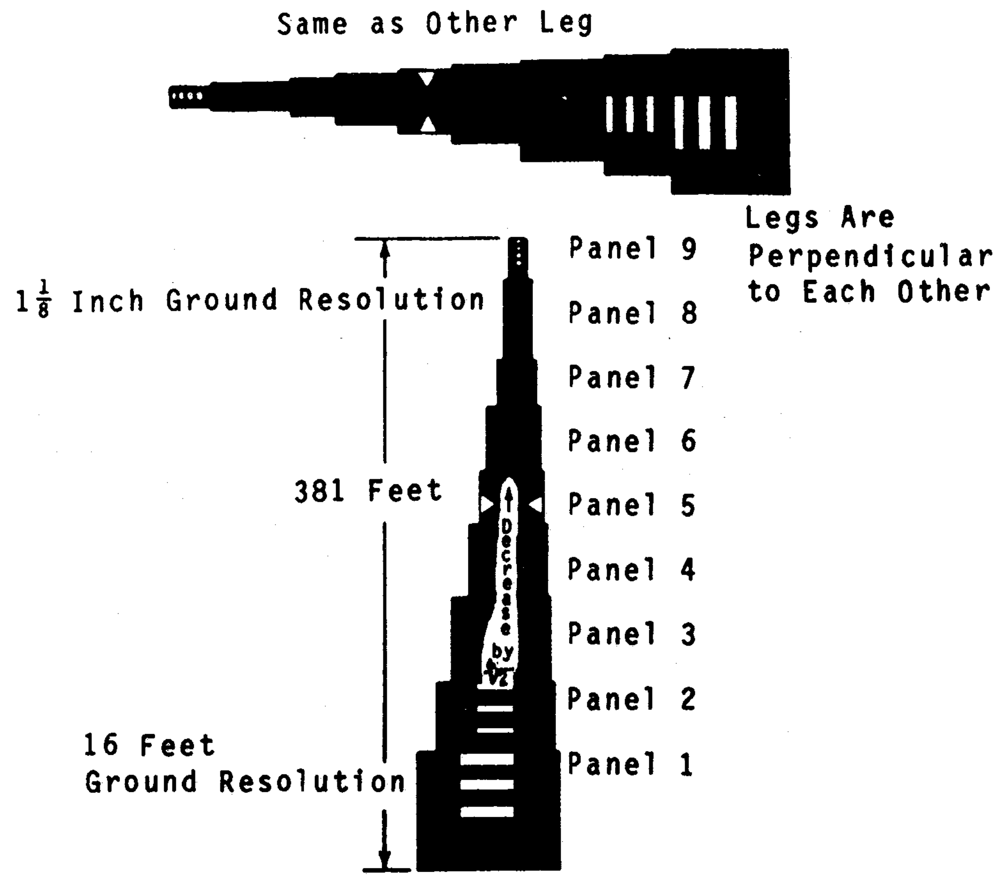

Figure 1.--Photo resolution target. The ground resolved distance range is from 1.12 to 192 inches (0.03 to 4.88 meters); contrast ratio is 5:1. Except for groups 1 and 2, bar sizes decrease by the sixth root of two. The target consists of two 381-foot legs, each composed of 39 gray bar groups on a black background. Each bar group is separated by a black space equal to twice the width of the succeeding smaller bar. The target normally is displayed with one leg parallel to the line of flight and the other perpendicular to it.

Interpreting Results

In interpreting these results, note that variations in resolution normally are expected between the along-the-line and across-the-line of flight orientations due to motion effects, and differences in resolution at various locations in the frame also are expected from normal and sometimes appreciable differences in optical (lens) performance over the format. The specific measurement of these variations is beyond the scope of this effort, and they have, in effect, been averaged out of the data. However, because of the small number of samples (only two images per photo scale, located at varying positions across the frame), the benefit of averaging the data is not very great and a significant amount of uncontrolled variations still can be present in the results.

The accompanying plots (figures 2, 3, and 4) provide the approximate net GRD values, in inches for the original negatives (or positives) and corresponding paper prints and at scales from 1:6,000 to 1:40,000 for color, color IR, and black-and-white IR films. These data are neither exhaustive nor definitive. They are the result of a single limited flight test and are presented to provide general information and orientation.

The GRD versus photo-scale graphs are plotted logarithmically because of the wide ranges of the values and the inherent logarithmic character of the data. These logarithmically plotted data tend to lie roughly along straight lines. When the negative and print trends are parallel, this indicates a constant percentage difference in GRD between the negatives and prints. The relative ability to see fine detail in the image also varies logarithmically with both the GRD and the photo scale. Therefore, the plotted trends also indicate this general ability.

Inspection of the color IR trends in figures 2 and 3 indicates approximately the same slopes and percentage differences between the negative and print trends for the two films. The color film shows an almost 20-percent GRD advantage over the color IR film. This is at least qualitatively consistent with the published film properties.

The black-and-white IR plotted trends in figure 4 have about the same slope as those of the other two films, but the original negative GRD values are worse than the values of both the color and color IR films. However, the GRD loss in printing is far less with the black-and-white IR, and the result is a paper print GRD level that is better overall than that of the other two films, as reported by a number of photo users in the Forest Service.

For convenience, the original and paper print GRD's are plotted separately in figures 5 and 6. In figure 5, the GRD advantage of the color film over the black-and-white IR is not consistent with the published resolution properties of the two films in this particular instance. It has not been accounted

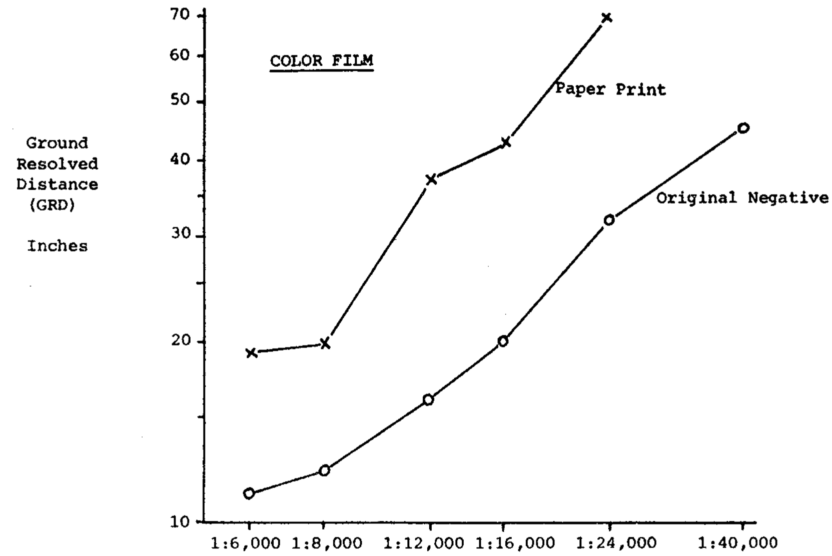

Figure 2.--Ground resolution of color photography at six different scales.

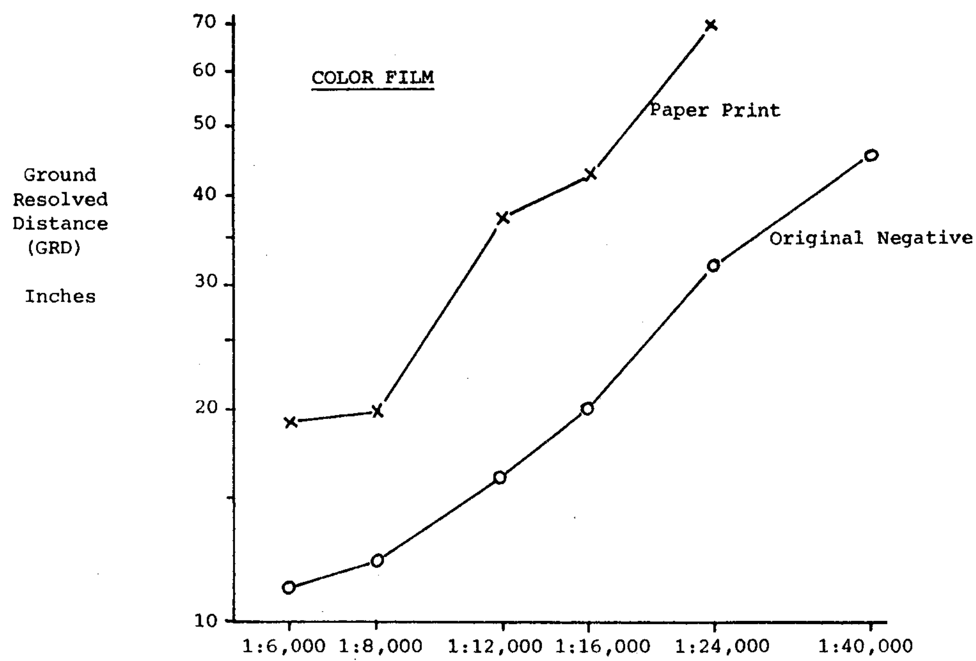

Figure 3. -- Ground resolution of color IR photography at six different scales.

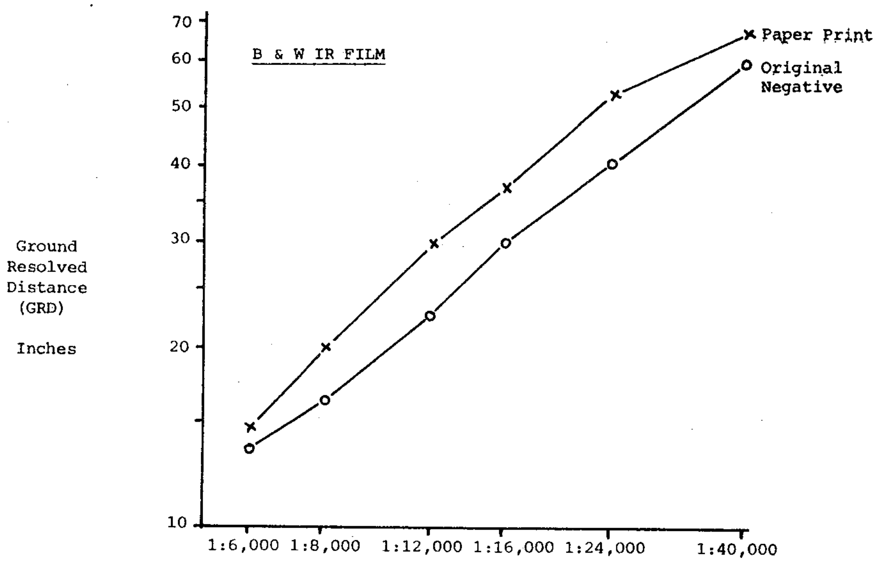

Figure 4.--Ground resolution of black and white IR photography at six different scales.

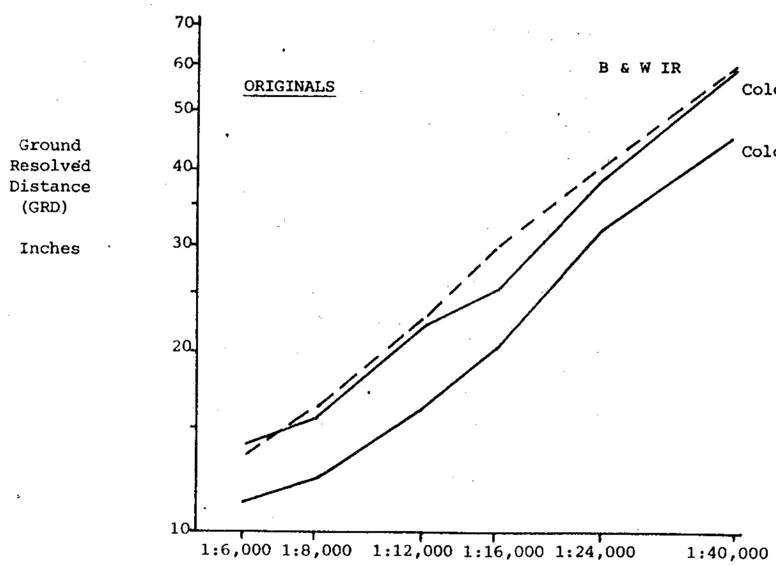

Figure 5.--Ground resolution of original camera product, three films at six different scales.

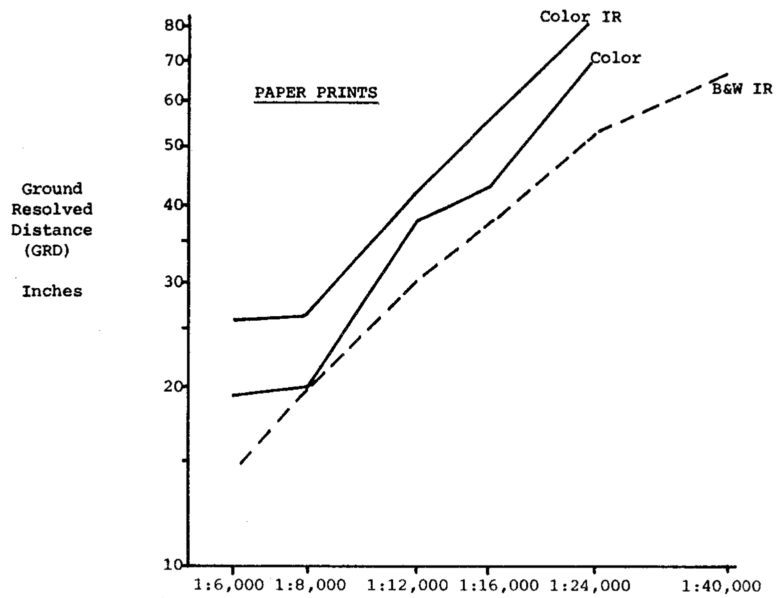

Figure 6.--Ground resolution of paper prints, three different camera films at six different scales.

for but could have resulted from a number of the uncontrolled aspects of this limited test. These could include variations in the apparent contrast of the resolution target, which is very important in resolution testing, resulting from differing spectral sensitivities of the three emulsions. Other factors may include differences in sun angle, as well as other variations in the flight and processing parameters. The three films were exposed in the same day: first color, then color IR, and then black-and-white IR.

This set of photography may be used for comparison or evaluation of other photography sets, scales, and emulsions. It is a valuable tool for training. The photography is available for purchase through ASCS under the following designation:

Area Code - 609002 Allegheny National Forest (Hallton 7 -minute quad)

Date - September 7, 1984

Frame numbers in table 1 indicate stereo-pairs that contain resolution targets. NHAP coverage for this site was acquired on May 6, 1983; code 471809; roll 323, frames 111-112 (HAP 83-F).

Table 1.--Stereo-pairs containing resolution targets.

Film	Roll	Scale					
		1:6,000	1:8,000	1:12,000	1:16,000	1:24,000	1:40,000
Color IR	384	31-32	41-42	48-49	53-54	58-59	62-63
Color	284	66-67	34-35	15-16	10-11	5-6	2-3
B-W IR	184	55-56	26-27	7-18	11-12	6-7	1-2

CONCLUSIONS & RECOMMENDATIONS

Acquisition, storage, and reproduction of aerial photography has been delegated to ASCS, and is handled at the ASCS-APFO at a reasonable cost to the Forest Service. Acquisition is a rather competitive business, highly dependent on weather and local conditions, and therefore variable in cost from Forest to Forest. Recent Federal Acquisition Regulations make selection of a reputable, low-cost contractor a more time-consuming task, requiring earlier and more careful planning for Forest Service personnel. Despite the increased work load, the percentage of contracts completed in a single flying season has increased in the past 2 years.

The ASCS-APFO facility in Salt Lake City is a production facility serving a large number of Federal, State, and private customers. To maintain a reasonable cost for photo services, the time spent per unit output is much lower when compared to other Federal custom laboratories.

Quality control of a contractor's deliverables and of prints going out to the Forests is a very important activity for both ASCS and the Forest Service. Forest Service personnel at both the Regional Offices and on the Forests need to convey their requirements to ASCS; ASCS in turn ensures that the contract is properly worded and that products meet specifications. Checking overlap, scaling, and labeling generally is easier than judging negative or print quality. Because of the lack of criteria for color quality comparison, the inspector usually subjectively judges whether a photo product is acceptable or not. The judgment of the user (Forester, Soil Scientist, and so forth) is important here since some photographic defects may be of minor importance in certain tasks. Forest personnel are infrequent purchasers of photography; therefore, they are not expected to be knowledgeable in all technical aspects. However, their involvement and awareness should be broader than at present, considering the importance of photography in their daily work.

The ASCS laboratory and quality assurance procedures are being handled properly--their personnel are helpful in routine as well as special projects and are willing to rectify any problems that might be caused in production. A comparison of ASCS photo products with those from another Government facility and from a private firm indicated ASCS products to be of equal or better quality. We found very few concerns about quality of photography in Regions that maintain close communication with ASCS.

Washington Office Engineering and ASCS offer the following recommendations on photo quality and related issues:

(1) Obtain more information on quality and timeliness of recently acquired photography. ASCS is including a short questionnaire with each photography shipment. This will provide feedback to ASCS and the Forest Service. Users who identify problems should send samples of photography to the Washington Office. Any problems identified this way will be discussed with ASCS, and solutions will be proposed.

(2) Improve communication between the Forest Service and ASCS. ASCS personnel suggest telephone contacts and visits (if possible) from Regional Office and Forest personnel. This is especially important when new photo orders are inspected. When submitting printing orders, provide samples of photos with the color balance that the Forest prefers. Other information of importance when acquiring new or existing photography is the intended use of the materials, as well as correct billing and shipping addresses.

(3) Forests or Stations planning to acquire new aerial photography should evaluate their requirements and review contract specifications. The contract specifications may be tailored to reflect specific needs of the requesting unit.

(4) The use of color IR film (2443) is increasing in the Forest Service. It is a color reversal film normally processed to a positive. Processing to a negative is discouraged by the manufacturer (no specifications exist), and by ASCS. The difference in price between prints from a negative and prints from a positive will decrease as the volume of orders for that service increases. ASCS currently offers lower prices to Forests for large-volume printing from positive film.

(5) Forest Service use of photography generally is limited to paper prints and simple photo-interpretation equipment. Except for special projects, we are not using what the latest photographic technology has to offer. The following items and activities can contribute to improved photo products:

(a) Higher resolution films.

(b) Wider use of transparencies.

(c) More sophisticated photo-interpretation equipment.

(d) Wider use of image motion compensation cameras to reduce distortions in the original film.

ASCS contract specifications call for periodic U.S. Geological Survey inspection/calibration of aerial cameras used by contractors. The procedure is described in the USGS Manual, "Calibration of Aerial Mapping Cameras" (PM1-2-5). We recommend tightening resolution specifications for cameras used for Forest Service contracts. This will eliminate some of the older cameras that just meet the current specifications and should produce sharper images on the original film. Combined with increased use of transparencies in addition to paper prints and better photo-interpretation equipment, this will give users more information per dollar spent on photography.

Determining the Critical Thaw-Weakened Period in Asphalt Pavement Structures

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Kootenai National Forest

INTRODUCTION

Unseasonably warm weather in January 1984 caused a thaw that weakened the asphalt pavement structure of the Yaak 92 Forest Highway on the Kootenai National Forest, Montana (see figures 1 and 2). The decision to impose vehicle load restrictions 3 to 4 weeks earlier than usual elicited criticism from local timber company representatives and construction contractors who regularly use the highway. Users generally accepted the inevitability of spring road closures, but they complained of insufficient forewarning to remove equipment from the field or to plan springtime mill operations. The users also expressed concern that the technical evaluations leading to the load restrictions were based on incorrect procedures and subjective judgments and that the shutdowns were premature. Although the controversy lessened considerably when visible signs of pavement distress developed within days of the closure, road users' concerns should be addressed in the future to avoid similar problems.

A program of monitoring temperatures throughout the pavement structure was devised in response to the concerns. The system combined the results of published research on the thaw-weakening phenomenon with practical instrumentation and monitoring efforts of agencies such as the Alaska Department of Transportation and Public Facilities. The instrumentation system now has operated on the Kootenai National Forest for 1 year.

Past research efforts to develop methods for identifying thaw-weakened conditions in pavement structures have resulted in complex, expensive, and labor-intensive procedures that are difficult to implement at the Forest level. Because the systems

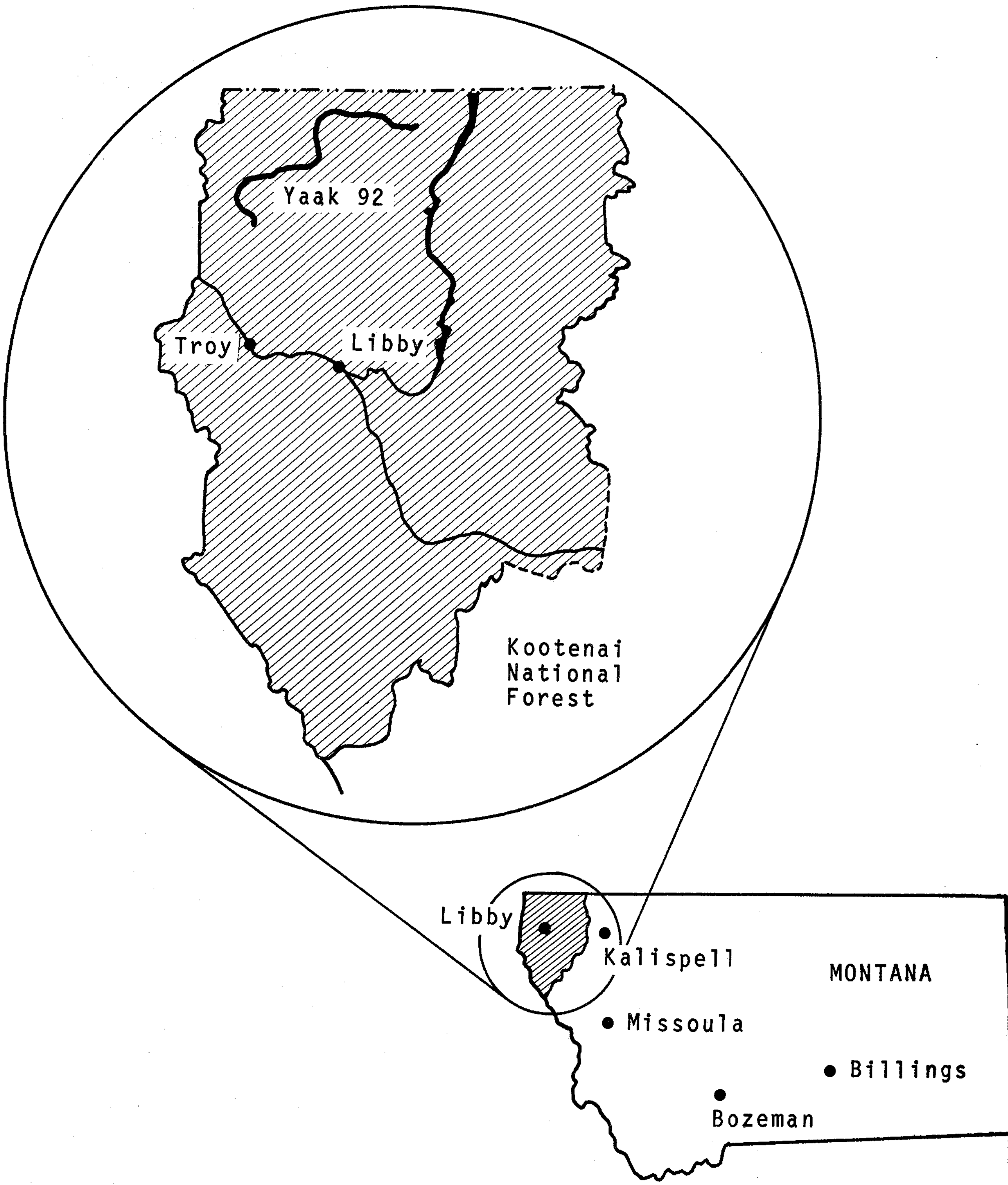

Figure 1.--Location map.

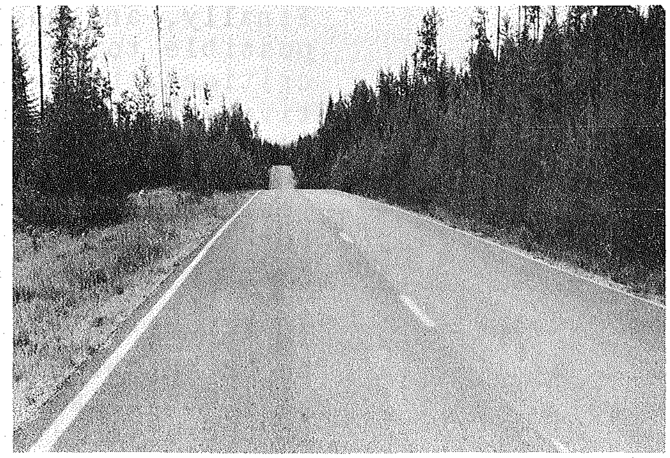

Figure 2.--Yaak 92 Forest Highway (view south from milepost 38.0).

are not easily understandable, public acceptance of road closure decisions based on these methods generally has been skeptical. However, the connection between temperature and thaw-weakening is more readily apparent to most individuals than the more complex concepts that address soil moisture and excessive pore water pressures. The program on the Kootenai National Forest now has been virtually totally accepted by industry. In fact, the most staunch supporters of this project were the worst critics of the subjective system used in the past.

The system components are inexpensive, so road systems can be completely instrumented at a very low cost. In addition, individual road segments can be managed separately. Forest Service personnel can leave portions of a road system open to commercial use but close other portions of the same system during thaw-weakened conditions. Conversely, a road system may be reopened in segments as the instrumentation indicates strength recovery in specific areas. The duration of closures may be shortened by the use of this system since the conservative subjective methods to determine unseen pavement weakening will no longer be necessary.

A single individual can gather the required field data while traveling to or from other projects; thus, time spent in the field is negligible. The data are rapidly reduced and plotted in the office and can be available to the appropriate decision-makers in minutes.

Finally, and most importantly, this system makes it possible to accurately determine the limits of the critical thaw-weakened period. Potentially destructive vehicle loads can be restricted during a more accurately defined time period, resulting in a reduction of spring thaw damage, a large savings in yearly maintenance expenditures on asphalt-paved Forest roads, and an extension of their serviceable lifetimes by years.

In short, this instrumentation system has proven to be acceptable to the public and industry; inexpensive to install and maintain; accurate; and simple to operate. It provides increased flexibility to Road Managers and promises future savings in road maintenance and reconstruction expenditures.

INSTRUMENTATION

The system consists of a series of thermistors used as temperature probes that are placed above, within, and below the asphalt mat. Thermistors, which are semiconductors whose resistance varies with fluctuations in temperature, can be used both in the ground and as air temperature sensors (see figure 3). These devices were selected because their cost was low, they were highly accurate and interchangeable, and they needed no special calibration or circuitry conditioning for operation.

Instrumentation at each site consists of a minimum of eight sensors (see figure 4). A thermistor placed approximately 4 feet above the ground surface monitors the air temperature. Air probes are inserted into the center of opaque plastic tubes and mounted in a shaded location to prevent inaccurate readings resulting from direct sunlight (see figure 5). A thermistor sealed within a 1.5-inch-deep saw cut made in the asphalt surface reads the mat temperature. This depth represents the approximate mid-point of the new 2.5- to 3.0-inch-thick hot-mix asphalt pavement recently completed on a large portion of the Yaak 92 Forest Highway. Each site also has a thermistor located immediately at the base of the mat. The spacing of succeeding thermistors follows a consistent sequence of 4, 9, 15, 21, and 33 inches below this sensor. At five sites, sensor strings are lengthened to include two additional thermistors 45 and 57 inches below the base of the asphalt. The exact depths of the temperature sensors are governed by the thickness of the mat. Figure 4 illustrates thermistor depths for an idealized 3-inch-thick asphalt structure.

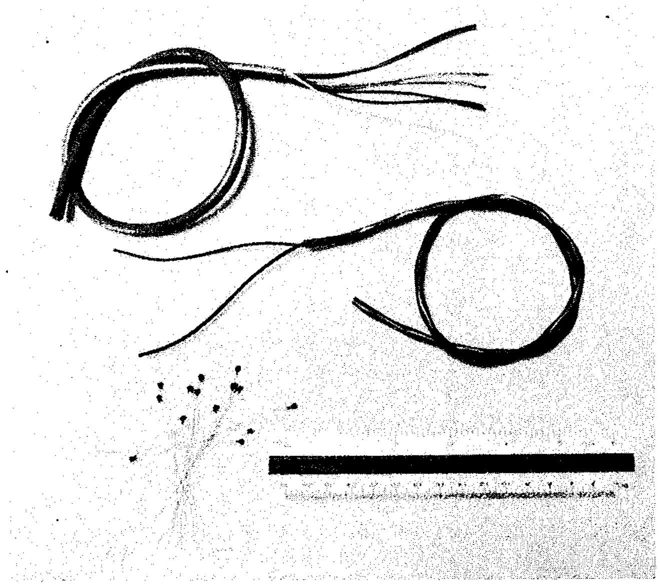

Figure 3.--Instrumentation components: thermistors, eight-conductor cable, and two-conductor cable.

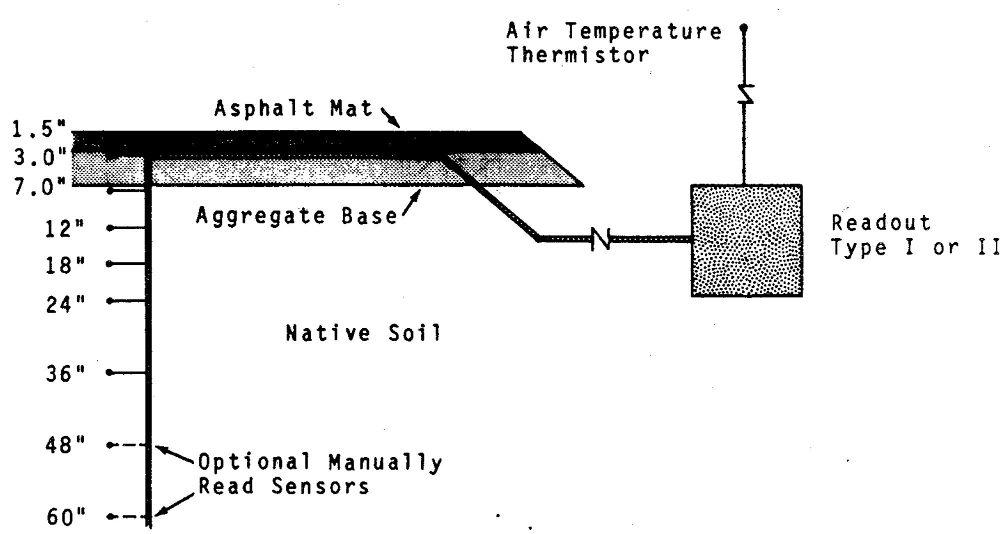

Figure 4.--Instrumentation schematic.

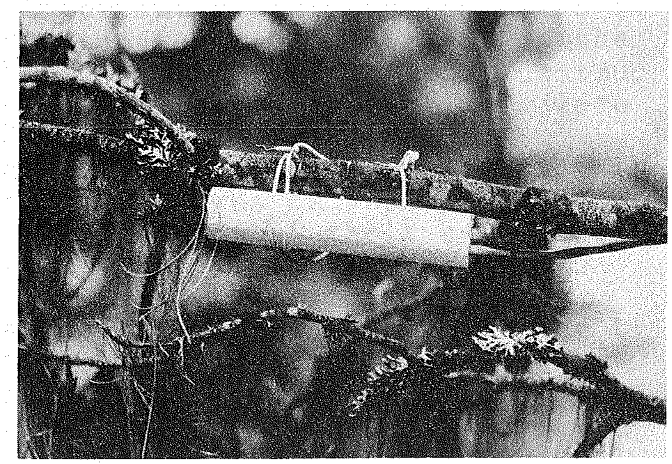

Figure 5.--Air probe, site D2-92-38.0.

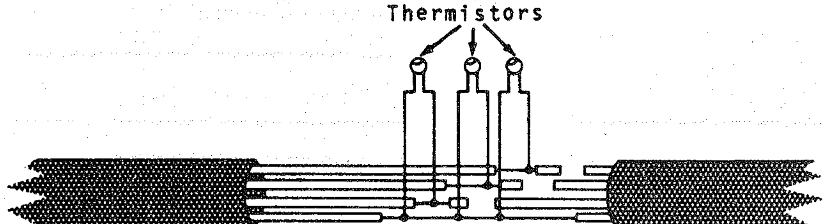

Figure 6.--Generalized thermistor string wiring diagram.

Ground thermistors are soldered into a multi-conductor cable consisting of eight 22-gauge, multi-strand, PVC-insulated copper wires. One wire serves as a common ground for all sensors. Each remaining wire is connected to the second lead of the individual sensors (see figure 6). Air probe thermistors and the two bottom sensors at the five extended sites are wired into two conductor cables. The eight-conductor ground cable and the two-conductor air probe cable end at a 10-pin female connector in a standard electrical junction box located at the side of the road (see figure 7).

Figure 7.--Junction box, site D-2-92-38.0. Note airprobe on branch slightly above and left of junction box.

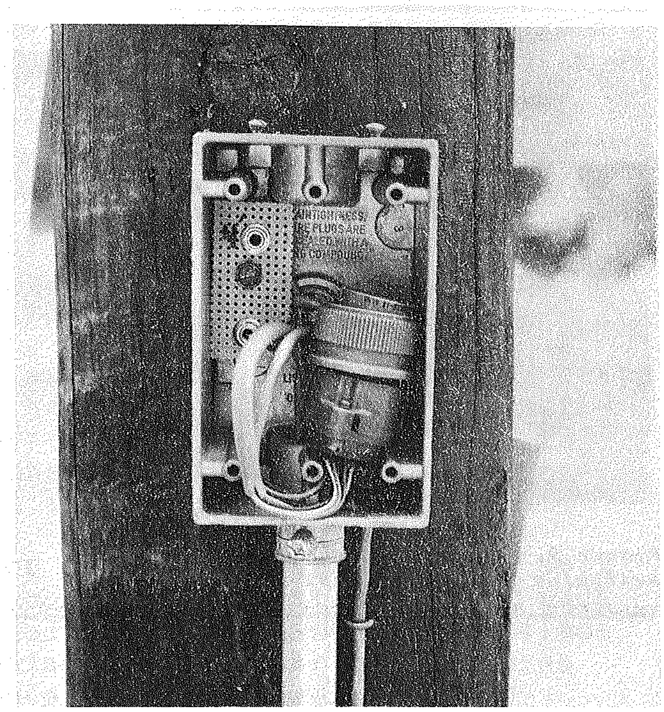

Figure 8.--Ten-pin female connector at instrument string terminus and phono jacks for reading the 4- and 5-foot sensors (site D2-92-23.95).

Forest Service personnel can monitor the site by removing the cover plate of the junction box and attaching the 10-pin connector (see figure 8) to one end of a switching unit. An electronic thermometer is attached to the other end of the unit (see figure 9). The thermometer measures the line resistance, converts resistance to temperature, and displays the temperature in degrees Fahrenheit. By rotating the dial selector on the switching unit, each thermistor on the string can be read sequentially. Extended strings are equipped with two phono jacks within the junction box; one connects to the 4-foot sensor, the other to the 5-foot sensor. To monitor these thermistors (see figure 10), the electronic thermometer is detached from the switching unit and coupled to the phono jacks.

FIELD INSTALLATION

The Yaak Highway was divided into segments, each of which could be closed independently without significantly affecting the use of remaining segments. Within each division, a minimum of two sites were selected for instrumentation. These represented

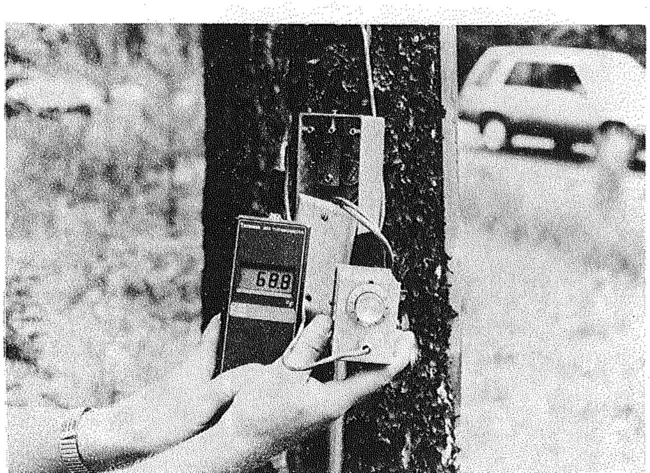

Figure 9.--Electronic thermometer and switching box (site D2-92-45.2).

Figure 10.--Electronic thermometer reading the 4-foot sensor (site D2-92-45.2).

areas anticipated to enter the critical thaw--weakened state early (sites exposed to direct sunlight for a large portion of the day) and areas expected to lag behind (shaded sites). In addition, instrumentation was installed in most major soil types and elevation extremes encountered along the Yaak Road. Seventeen instrument sites, at an approximate density of one site per 3.5 miles, were installed during fall 1984 along the Yaak 92 Forest Highway and adjacent paved roads.

The instruments were installed through an approximately 1.5-inch saw cut in the pavement surface extending from the intended instrument string location to the road shoulder. A wireline core-drilling unit was used to bore a 3.0-inch diameter hole centered on the end of the saw cut through the asphalt to the monitoring depth. The string was placed in the borehole, the hole back-filled with a silt-sand mixture and compacted with a wooden dowel and rubber mallet, and the cable routed through the saw cut to the edge of the pavement. Cold-mix asphalt was used to patch where the borehole penetrated the mat and asphalt crack sealer was used to enclose the instrument cable within the saw cut. The cable was buried in a trench from the road shoulder to its end in the electrical junction box, the air temperature probe installed, and the final solder connections joining the air and ground cables to the 10-pin connector completed the process. Installation progressed at the rate of five to six sites per day.

TESTING & MONITORING

Tests were performed on soil samples obtained from 8 of the 17 sites to determine the freezing point of local soil moisture. The presence of dissolved minerals can depress the freezing point of water below the laboratory distilled value of 32 degrees Fahrenheit, so it was necessary to determine the actual temperature value to use while monitoring the critical period. Also, because of the dynamics of freezing and thawing water, a significant amount of time would pass (with thawing and associated structural weakening occurring) if too high a freezing value was assumed during monitoring. Test results indicated that the freezing point of soil moisture throughout the project area was 31.7 to 31.8 degrees Fahrenheit. A value of 31.7 degrees Fahrenheit was used in all subsequent analyses.

Beginning in October 1984, air, pavement, and soil temperatures were recorded at least weekly at each site. This increased to approximately three times per week per site as ground and air temperatures rose immediately before spring thawing, which occurred in March 1985. Accessibility problems caused by heavy snows and unplowed roads limited monitoring frequency at four of the sites to once per week throughout the winter and spring.

Pavement strength was measured by a series of Benkleman Beam deflection tests throughout the critical period and related to the progression of the depth of thawing (see figure 11). Deflection data were reduced using the ELSYM5 elastic layer analysis program and an IBM-PC microcomputer to determine changes in stresses and strains at the base of the asphalt mat during the critical period. The ELSYM5 program also allowed analysis of multiple-wheel load deflections derived from the three-axle nonstandard test vehicle. Deflections alone were not included in the final analysis because maximum deflections do not necessarily coincide with maximum strain values at the pavement base. Deflection testing began in late fall 1984, ceased during the winter months, and recommenced in spring 1985. Deflection data were obtained at least weekly at accessible sites throughout the critical thaw-weakened period.

Samples of asphalt and base course materials were submitted to Forest Service laboratories in DuPont, Washington, and Missoula, Montana, for dimetral testing. Resilient Modulus values thus obtained were used as input to the ELSYM5 computer program to more accurately model field conditions.

Figure 11.--Benkleman Beam deflection testing (site D2-92-45.2).

RESULTS

The weighted average soil temperature was calculated from readings obtained from the six thermistors beginning with thermistor number 2 at the base of the mat and ending at thermistor number 7, located approximately 36 inches below the road surface for each site for each monitored date. Figure 12 illustrates the change in this average temperature from early October 1984 through late April 1985 at site D2-92-30.6. This plot is representative of all noninsulated (plowed) sites. Thawing began when temperatures of 31.7 degrees Fahrenheit occurred at the base of the asphalt. As illustrated in figure 13, thawing of the base did not begin until the average soil temperature rose to approximately 30 degrees Fahrenheit. This seems to be a consequence of the frozen material's efficiency in distributing incoming heat until sufficient energy has accumulated in the pavement structure to permit melting of the base.

These initial results strongly suggest that by developing graphs similar to figure 12 through late winter and early spring, it will be possible to project the approximate date soil temperatures will reach the 30-degree threshold and to predict within close limits when spring thawing will begin. The specific time can be identified by thawing temperatures recorded at the base of the asphalt. Road users can be notified in advance of impending load restrictions and the beginning of spring thaw can be shown objectively. In addition, the effects of short-term weather changes, such as the "January thaw" of northwestern Montana, on instrumented roads can be evaluated accurately.

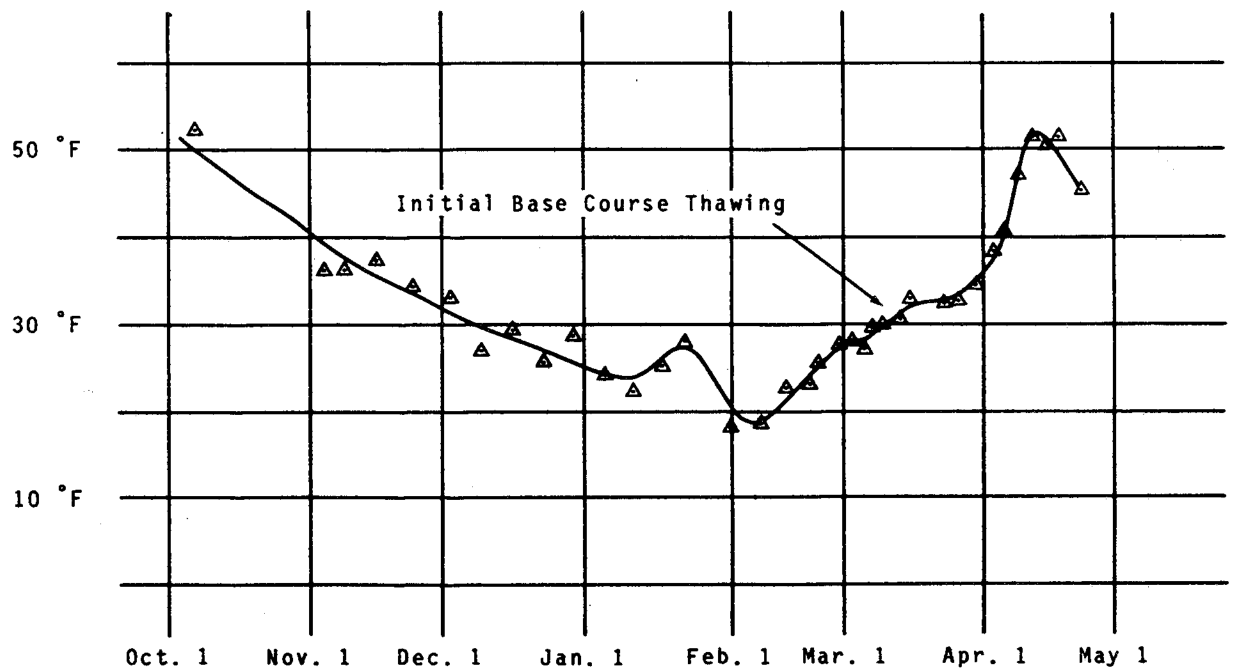

Figure 12.--Average soil temperatures from the base of the asphalt to a depth of 3 feet (site D2-92-30.6).

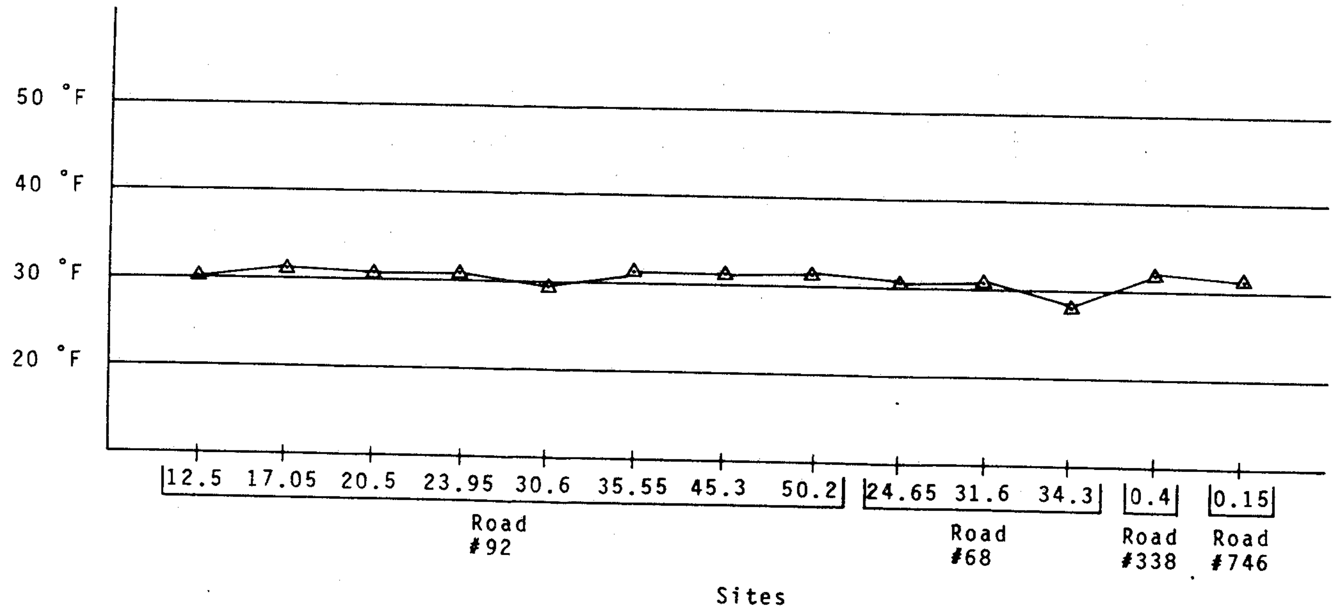

Figure 13.--Average soil temperatures at the commencement of base course thawing.

The identified relationship between depth of thaw and pavement strain allows using the soil temperature profile to monitor strength variations during the critical period. Figure 14 illustrates this relationship at site D2-92-23.95. To better present strength loss and gain in a pavement structure, strain values derived from the ELSYM5 computer reduction of Benkleman Beam deflection measurements were used to calculate road damage factors. A factor of 1.0 was assigned to the 18-kip equivalent loading value of the test vehicle when the pavement structure is in its fully recovered state (late summer). Damage factors other than 1.0 indicate the increased or decreased loading in 18-kip equivalents required under summer conditions to duplicate the calculated horizontal strain at the base of the asphalt for a given test date. The horizontal strain values were derived from the ELSYM5 computer analysis of measured Benkleman Beam deflections. Values above 1.0 indicate a progressively weakening structure; those below 1.0 indicate increasing strength from the presence of frozen ground directly beneath the mat. For example, a factor of 1.0 would indicate the relative impact on the road caused by a passing vehicle during the period of the pavement's maximum structural strength in late summer. A factor of 10.0 indicates that strength loss is such that the same vehicle has 10 times the pavement impact (damage potential) when compared to late summer values. The peak value on figure 14 indicates that while the pavement at this specific site was at its weakest observed state, the above vehicle would cause 17.3 times the impact relative to the recovered condition. Calculations of the damage factor were based on the 48,000-pound, 3-axle Benkleman Beam test vehicle using AASHTO 18-kip equivalent axle loads.

The rapid pavement strength loss accompanying the onset of thaw in the base course was typical for all sites tested and monitored. Within a very short time, the load-carrying capacity of the pavement had dramatically decreased. The importance of placing vehicle restrictions at the beginning of base thawing is graphically illustrated by figure 14, as even short delays will result in heavy vehicular loads travelling over a substantially weakened structure. This study's findings are consistent with conclusions reached in past research projects, indicating pavement strength loss progressing swiftly as the base course begins to thaw.

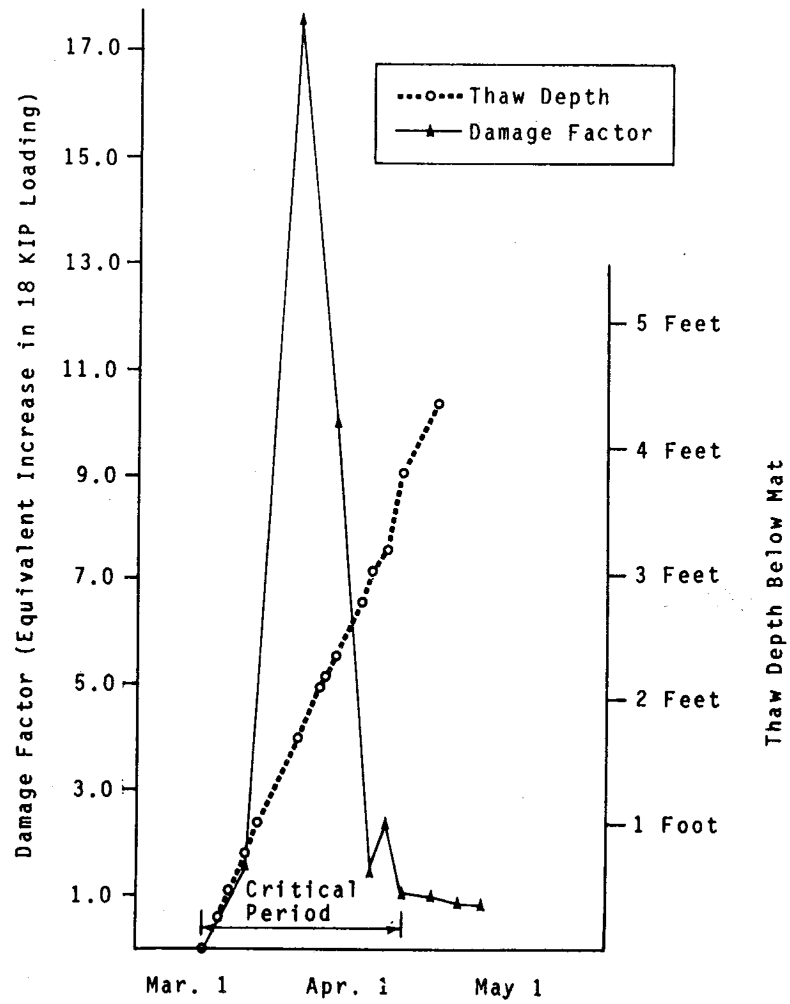

Figure 14.--Damage potential versus thaw depth (site D2-92-23.95).

Strength recovery for all sites occurred with the same general pattern: an initial rapid strength gain followed by a period of more gradual improvement. At sites underlain by nonplastic soils, the change from the rapid primary recovery to the slower secondary recovery occurred when pavement strain values had returned to approximately fall values (damage factor less than or equal to 1.0). Thaw depths at the point of this change had progressed to approximately 4 feet below the asphalt mat (see figure 14). Data gathered after the first season of instrument monitoring strongly indicate that for pavements underlain by nonplastic soil, adequate strength recovery has been achieved to allow removal of load restrictions when thawing reaches a depth of 4 feet. This is in close agreement with the results of similar studies performed by the State of Alaska Department of Transportation and Public Facilities.

At sites underlain by soils exhibiting plastic properties, the change from primary to secondary recovery rates occurred at some strain value greater than the fall value (damage factor greater than 1.0). Currently, data are insufficient to establish a reliable correlation between pavement strength recovery and depth of thaw under these conditions.

CONCLUSIONS

These results were obtained from one season of monitoring asphalt and soil temperatures as indicators of pavement structural strength during the spring thaw period. They suggest that Forest Service Road Managers now have a tool they can use to address past problems with seasonal load restrictions. By monitoring average soil temperature changes through the late winter and early spring, Road Managers can make a reasonable prediction of the expected onset of pavement weakening. Road users now have the opportunity to remove equipment from the field and to plan their spring activities. The beginning of spring thaw can be accurately and objectively confirmed by the occurrence of temperatures above the freezing point of local soil moisture measured at the base of the asphalt mat. In areas of non-plastic soils, the recovery of pavement strength can be determined indirectly by monitoring the depth of thaw. When thawing progresses to approximately 4 feet below the base of the asphalt mat, vehicle load restrictions can be removed. Finally, this method can be used to evaluate the effects of short-term weather fluctuations on pavement load-carrying capacity. Implementing this inexpensive system could result in large decreases in annual maintenance costs and extended road serviceability. The system's installation cost per site in 1984 was approximately $240.00, including all parts, equipment, and labor. Although sites were selected for instrument string installation for this study based on a combination of criteria (including exposed/sheltered locations within given road segments, soil types, and elevation extremes), a practical monitoring system need only include sites anticipated to enter the spring thaw-weakened state early (exposed sites) and late (sheltered sites) within given road management segments. The actual instrument density would depend on the length and number of road segments selected.

SUGGESTED FURTHER STUDIES

We suggest additional studies to confirm the correlation between depth of thaw and pavement strength recovery in geographical areas outside northwest Montana, to check the reliability of projecting average soil temperature to predict the onset of the spring thaw period under a wider variety of climatic conditions than was possible in the present program, and to test the results obtained from variations in the thermistor spacing on the instrument strings. In addition, the relationship between thaw progression and pavement strength recovery in areas underlain by plastic soils needs a more thorough investigation.

An automated data recorder developed as part of this study is being field tested on the Kootenai National Forest. The device is designed to gather and store temperature data for later retrieval, making manual monitoring unnecessary. We will make the results of these trials available at a later date.

Information regarding assembly, installation, testing procedures, component suppliers, and approximate costs for this system is available from the authors.

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