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Engineering Technical Information System

Awards for the 1986 <i>Field Notes</i> Articles	1
Robert S. Black—Forest Service Engineer of the Year	3
Yakutat Global Positioning Project	5
Mount Whitney Solar Toilet	13
An Empirical Evaluation of Network Analysis Models Used by the Forest Service	21
Skyline Thinning Cost Comparison for Three Yarding Systems	
HP-41C Estimate of Uncertainty for Conventional Ground Method Closed Survey Traverses	47
A Primer on Satellite Sensors	59
Central Tire Inflation Program— Boise National Forest Field Evaluation	

Awards for the 1986 *Field Notes* Articles

Thanks to the efforts of those readers who took the time to fill out and submit rating sheets, we can now announce quite unequivocally that the following articles were found to be the top three of 1986:

DRUM ROLL,
PLEASE!

<u>Article</u>	<u>Author(s)</u>
ASNAP: Administrative Site Needs Assessment Process	Lynn Kanno Civil Engineer Los Padres National Forest Region 5
Decisions...Decisions... Decisions	Jim Suhr Civil Engineer Region 4
Evaluation Report--Computer- Aided Drafting/Design for Use by Forest Service Architects and Structural Engineers	Nelson Hernandez Structural Engineer Region 5 Maurice Hoelting Architect Region 8 Robert Sandusky Regional Architect Region 5 Stephen Sichau Supervisory Electrical Engineer Region 6

Congratulations to the authors of these articles and special thanks to all the others who made the time to write and submit articles to Engineering Field Notes. We appreciate your willingness to share your ideas and experiences with others and the extra effort you put forth to do it.

Remember, every reader is a potential author of an Engineering Field Notes article. If you've had an interesting experience or have some information that may be of interest to Engineering Field Notes

readers, why not submit it for publication? We'll be waiting to hear from you!

A NOTE to
EFN's READERS

Really--we do want, and need, to hear from you. And you don't need to be a professional writer either. A 1- or 2-page article on some aspect of your Engineering work that you feel would interest others would really be appreciated. Double spaced/single spaced/by DG/by the overland route/typos/no typos--it doesn't matter. We'll do our best to help you share your experiences and to share others' experiences with you.

EFN

Robert S. Black—Forest Service Engineer of the Year

On February 18, Bob Black, Forest Engineer on the Six Rivers National Forest in Region 5, received the "Forest Service Engineer of the Year" award at the 8th Annual NSPE Federal Engineer of the Year Awards Ceremony in Arlington, Virginia.

Following is a brief statement of Bob's recent achievements:

ROBERT S. BLACK, USDA Forest Service. Forest Engineer, Supervisor, Civil Engineer, Six Rivers National Forest, Eureka, California. B.S., Logging Engineering, Oregon State University. Mr. Black exhibits a rare combination of technical skills and common sense and acts with a determination to innovate and get things done. In 1983, after the USGS issued a state-1 volcanic alert for California's Mammoth Lakes area, and at the request of the FHWA, his engineering unit on the Six Rivers National Forest took the lead in locating and designing the "Mammoth Alternative Access Route," which could save the 40,000 area residents and tourists in the event of a cataclysmic eruption. Using both unconventional photogrammetric techniques and an interactive, micro-computer based graphic road design system, he initiated the successful 6-month design and construction of the access route--saving \$200,000 and 11½ months off both FHWA and Cal Trans estimates for designing and building that route. His leadership in the economic planning and design of rural, low-standard roads is evidenced by his selection to his Agency's National Roads Program Productivity Improvement Team--the technical/managerial recommendations of which should save the Agency an estimated \$20 million annually.

The Awards Ceremony was the highlight of this year's "National Engineers' Week," which was celebrated from February 22 through 28.

More than 30 "Engineers of the Year" represented their respective Agencies at the ceremony. Dr. C. D. Kealy, Mining Engineer with the Bureau of Mines, was named "Federal Engineer of the Year." Dr. Kealy is recognized as a leader in mine geotechnical engineering.

During Bob's visit to the Washington Office, he accompanied Engineering Director Sterling Wilcox to a morning NFS Staff session, a Chief-and-Staff session, and a Roads Briefing that was given to Assistant Secretary Dunlop and Deputy Assistant Secretary MacCleery. Bob also was the guest of honor at the Washington Office Engineering Staff "Engineers' Week Social."

Our sincere congratulations to Bob on receiving this prestigious award and well-deserved attention.



Figure 1.--NSPE President Joseph H. Kuranz, P.E., and Forest Service Washington Office Director of Engineering Sterling J. Wilcox present Bob Black with plaque distinguishing him as Forest Service Engineer of the Year.

Yakutat Global Positioning Project

*Dave Wood
Land Surveyor
Region 10*

INTRODUCTION

During the winter of 1985-86, the advance of the Hubbard Glacier (figure 1), which is located 25 miles north of Yakutat, Alaska, accelerated, and its forward movement began to close off the mouth of Russell Fiord. Glacier movement was measured at as much as 40 feet per day during peak periods. On May 29, the glacier completed its advance across the entrance of Russell Fiord, forming a glacial dam at the northern end and changing the fiord into a 76-square-mile lake. The runoff from spring rains and snow melt caused a steady water rise of as much as 1 foot per day. A water level of approximately 185 feet would cause an overflow at the south end of the lake, and with a lake water level of 70+ feet in August, it appeared possible that an overflow could occur by fall 1987.

An overflow almost certainly would enter the Situk River, one of the richest fishing streams in Alaska. The additional water and current likely would scour out the salmon spawning beds and seriously damage this resource. This was of great concern to the people of Yakutat, because the Situk River contributes heavily to the economy of the town. Not only is the river a source for commercial fishing, but thousands of sport fishermen visit Yakutat yearly to fish this stream. Guide services, motels, restaurants, air taxis, and charter boats all benefit from the Situk River. It was predicted that the river would take several years to recover partially from the flooding and many years, if ever, to regain existing productivity.

The PLANNING STAGE

Russell Fiord and the Situk River both lie within the Tongass National Forest, so the Forest Service has a strong interest in controlling or mitigating environmental damage. In examining every known alternative to save the Situk River, it seemed that a diversion at the point of overflow would be the most effective and long-lasting solution, but existing 100-foot-

interval U.S. Geological Survey (USGS) contour maps were not detailed enough to evaluate overflow routes and develop mitigation plans for the Situk drainage or Yakutat foreland. New maps were requested to provide adequate floodplain analysis. The Forest Service and the U.S. Geological Survey agreed to combine efforts in the mapping project; the Forest Service would be responsible for the necessary control work and USGS would do the mapping.

USGS immediately sent the Forest Service work maps and aerial photographs showing all control points needed for the mapping. USGS needs, coupled with some Forest Service needs, made a total of 26 horizontal control points and an additional 57 points needing only vertical data. With a total of 83 control points to establish, the Forest Service quickly ruled out any conventional means of acquiring this information and decided to consider using a Global Positioning System (GPS).

Although the Region had no hands-on experience with GPS, information received from other users and firms offering the service was positive enough that the Forest Service was convinced that GPS would be not only more accurate, but also faster than any other means. Since this project is in a remote area with few roads, nearly 100 percent helicopter time would be required, no matter what means of survey was used. Selecting the most expedient method would therefore result in a savings.

One major concern with using GPS was the time of year that the project would have to be done--September. Since the Block I satellites used for GPS currently number only seven, they are visible only at certain times of the day in any one location. This observation period, known as a "window," opens twice a day in Alaska. Only one window was usable on our project because the other fell at night, when we could not fly. On September 1, the working window was approximately 5 hours long and opened at approximately 8:00 a.m. The window moves earlier by 4 minutes per day, meaning that by September 15 it would open around 7:00 a.m. and by the end of September it would begin at 6:00 a.m. While the window is moving one way, daylight is lost at the rate of 4 to 6 minutes per day. Some observation time would be lost as the month of September wore on.

The SURVEY

The decision to proceed with the project was not made until late August. The Forest Service contracting section did an exceptional job of getting this unusual contract let in a very short time. With speed mail and the cooperation of potential contractors working over the weekend on proposals, the entire process took less than 10 days. The proposed contract starting date was set for September 2.

Two people from the Forest Service Regional Office engineering unit in Juneau flew to Yakutat on August 25 and met with an individual from the USGS mapping division in Denver. This person is thoroughly familiar with USGS field procedures and input requirements for preparing maps. The entire project was reconnaissanced by air, using the work map and aerial photographs. Both the map and the photographs were marked with the general location of proposed control points. Once this location was found, the control point was selected. Final location was based on ability to view satellites from the point to be occupied and to identify the point on an aerial photograph. The contractor had furnished a printout and sketch map showing the paths of the satellites with azimuths and elevations plotted for every 2.5 minutes. This made it very easy to determine whether and how much brushing was needed. Fortunately, most control points were located on the beach, in muskeg, or in mountain alpine, which required little or no brushing.

Steel rods were driven in the ground at each point and a lath containing the point identification number driven nearby. Fluorescent ribbon was used generously to outline the area, so it could be found again as quickly as possible from the air. Each horizontal control point also was marked with a 30-foot target and photographed from 2,000 feet above. This provided easy photo transfer and ensured the position on the ground. All preliminary work was completed before the contract startup date.

Geo-Hydro, Inc., received the contract for the lease of three Trimble 4000S GPS units, and the contract required a positional accuracy of ± 1 foot. Because of the technical complexity of operating these units, the contractor sent a field expert with the equipment. His duties included training people in the use of the equipment, trouble shooting, and processing the data so that same-day results were available. On this project, the field expert was

invaluable. His knowledge of the operation of the receivers and computers was such that many problems were easily and quickly solved with just a few words of instruction. The training that the operators received was limited only by the amount of time they chose to spend. After 1 or 2 days of training, most operators were ready to go to the field. This training provided good general working knowledge, but in no way prepared the operators for all of the problems they encountered in the field. Without the field expert, many observation periods (referred to as "sessions") would have been lost.

This project was delayed a full week by unexpected events. The field expert could not get to Yakutat until September 4. He came from Edmonton, Alberta, and was traveling with the equipment until the plane landed at Juneau, Alaska. U.S. Customs then held the equipment while he went on to Yakutat. With no one to sign the release, Customs continued to hold everything. It took several days and many phone calls to get the equipment released. Once released, the equipment continued to sit in Juneau, because Alaska Airlines (the only commercial airline serving Yakutat) would not carry the extra freight. It seemed that every flight coming into Yakutat was at capacity with sport fishermen and their baggage and gear. We finally chartered a plane to bring the equipment to Yakutat. Operator training took place on September 8 and 9 and the project started on September 10.

A control traverse was run through all points requiring horizontal data. This was done using a translocation method, meaning that one GPS unit (sometimes referred to as the master) occupies a point with known values (a triangulation station), and one or more additional (slave or rover) units occupy desired points. Once a session has been completed, the most forward unit holds that point while the other unit(s) leapfrog ahead and repeat the same procedure until the original station has been reoccupied. When using translocation, all units must interrogate the same satellites during the same period of time. During this project, traverse points were occupied for as close to 60 minutes as possible.

Information received before the beginning of the project indicated that only a 60- to 70-percent success rate could be expected when traversing. ("Success rate" means that sufficient data are

collected to call a particular line good.) This proved true on this project. Of many possible reasons for failure to obtain sufficient data, the two most important reasons for success or failure on this project were good communications and reliable transportation.

As mentioned earlier, all units must be locked onto the same satellites and collect data for the same period of time when traversing. Unless all operators can talk with one another, this is nearly impossible; the best laid plans will fail unless everyone is communicating with one another. There is never a guarantee that each operator will come on line at a planned time. One operator mistake, a faulty disc, a malfunction of one receiver, or a number of other things can cause an operator to begin data collection either later than planned or not at all during an observing session. When using three units, as on this project, if the middle unit fails to collect data, two line measurements are lost and the only measurement achieved is one from the master station to the second rover unit. In other words, a point on the traverse is skipped. When this happens, all three points must be reoccupied or the middle point must be tied into the traverse in some other manner.

Communications with the field expert will save many sessions. Just a few words of advice over the radio can correct problems that an operator with limited training would rarely solve alone.

Good communications with the helicopter crew were a must throughout the project. Standard Forest Service handheld radios were used, but there were no repeaters in the area, which severely limited the range. Operators could communicate only in a direct line, which rarely worked, so the helicopter was used as a repeater by staying aloft during the early part of a session or by parking on a high point nearby. This was not totally effective, as the helicopter crew literally had to repeat everything said and some technical advice was sometimes lost or had to be repeated several times. This procedure also adds expensive flight time to a project. A repeater was installed about halfway through the contract and proved to be much more effective.

It was essential that the helicopter crew had a plan of survey each morning and knew enough about the project and project area to be flexible to change. With proper communications, the helicopter crew knew

which operator(s) to pick up and at what time. The crew also knew the location of the next points without having to search for them. After dropping the operators off for a session, the helicopter crew then would search out the points to be used during the next session. This enabled them to provide operators with a quick flight between points. The more time the operators spent on the ground, the more sessions they had and data they collected.

When a project involves a helicopter, not only does the ship and crew need to be reliable, but also the weather. Southeast Alaska never has reliable weather unless the prediction is for rain. While weather does not affect satellite observation, it severely hampers air travel. The Yakutat area is plagued with rain and low cloud ceilings for much of the year. Fortunately, the month of September this year provided more clear skies and sunshine than had ever been recorded in Yakutat, which enabled more flights than could be expected ordinarily. The project did suffer some from the clear weather, because at this time of the year the air is cooling, and early morning fog is common and often does not burn off until noon or later. Several sessions and some complete days were lost to weather.

The nature of GPS surveying, at this time and with the limited window, is to always be in a hurry. Operators must get to the point as quickly as possible, set up a tripod and antenna, connect power into the receiver, connect a cable from the antenna to the receiver, connect a cable from the receiver to a computer, and program both the receiver and computer before data collection can begin. Trying to make the equipment pay for itself on the ground is a continual concern. This leaves the door open for a great deal of human error. The equipment is user friendly, but there are still many errors to be made if an operator is not fully concentrating on the work. Forgetting one piece of equipment, not hooking up a cable properly, touching the wrong key, writing down the wrong station number or date, and failing to have properly formatted discs are among a long list of errors that can ruin the session or the day. Operators need to take the training seriously and to be as knowledgeable and comfortable (but not too comfortable) with the equipment as possible.

Another problem to be aware of, especially if trying to work during a weekend, is the possibility of the Department of Defense altering orbits or shutting

down one or more satellites. With the limited number of satellites in the sky, it doesn't take too many sick or stale satellites to ruin a day.

SUMMARY

The project at Yakutat took a total of 26 working days to complete and ended on October 7. This included establishing 83 control points plus the necessary ties and a base of bearing between two observed, second-order triangulation stations. The 57 points requiring only vertical data were done with a side shot method. This is a faster method than traversing in that one receiver remains on a known point and rovers move at will, occupying as many points as possible for at least 30 minutes each. Once again, each rover unit must be locked on the same satellites as the master. During the course of the day, all seven satellites will be used at one time or another, but with each operator familiar with the satellite pattern and with good communications, everyone will know when to change satellites. The success rate was much higher during this portion of the project. Operators were more familiar with the equipment, and the experience of solving earlier problems contributed to this success. As with many uncommon jobs, just when one becomes somewhat proficient, it's over.

EFN

Mount Whitney Solar Toilet

*James G. McDonald
Civil/Sanitary Engineer
Inyo National Forest*

*Robert Stanley
Wilderness Area Manager
Inyo National Forest*

*Dave McCauley
Staff Engineer
Pleasant Hill
Engineering Center
Region 5 Regional Office*

The solar toilet is located on the Mount Whitney trail within the John Muir Wilderness in the Inyo National Forest (figure 1). The toilet is receiving heavy use by hikers at a camp that is more than 10,300 feet above sea level (15,000 hikers use the trail every year). More than 1,000 gallons of waste are deposited each year, which is equivalent in waste strength to 120,000 gallons of water-borne domestic sewage. The area has very little soil for disposing human waste.

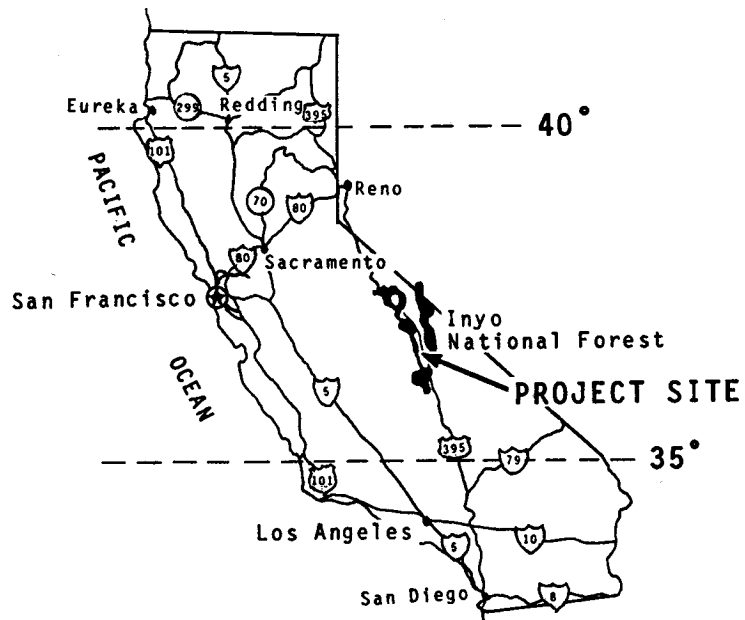


Figure 1.--Map showing location of solar toilet project site.

Before installation of the solar toilet, a helicopter was used to fly out 55-gallon drums of liquid waste from primitive vault toilets (figure 2). This operation was too expensive and not in tune with the wilderness concept.

In a test, the solar-driven toilet evaporated human wastes more rapidly than expected. The results of the test were so good that the Forest Service constructed two additional units with minor modifications (figures 3 and 4) and will save \$10,000 per year because the helicopter operation has been eliminated.

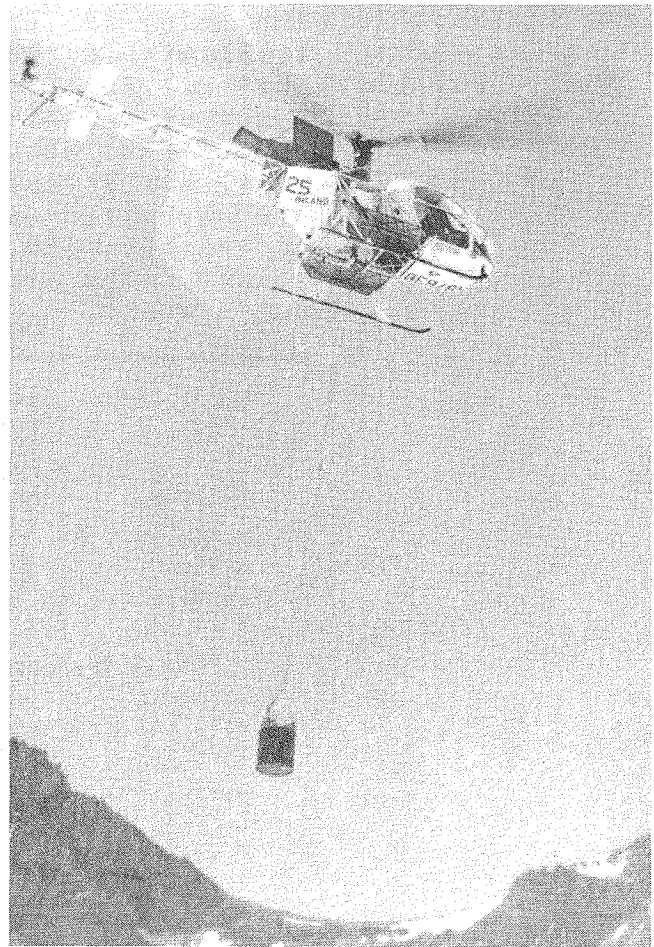


Figure 2.--Helicopter removal of liquid waste drum.

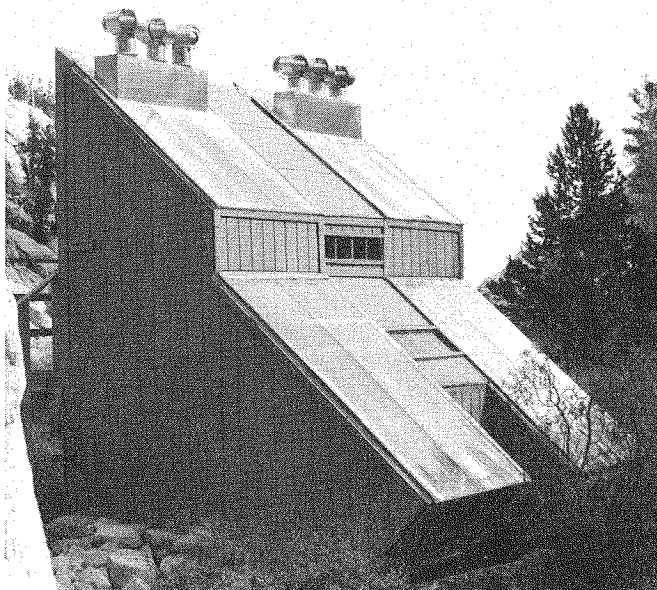


Figure 3.--Two solar toilet units tied together with glazed surfaces displayed.

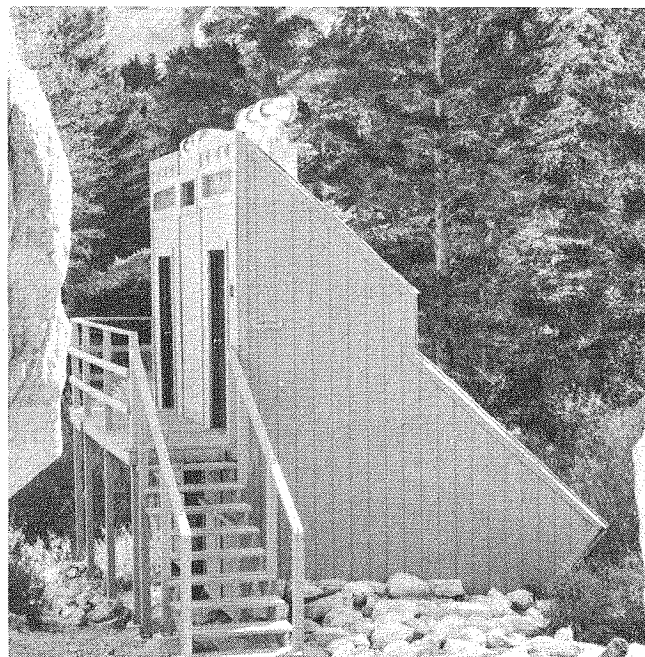


Figure 4.--Toilet entrance.

HOW IT WORKS

To the user, the unit is a vault toilet. The solids and liquids fall into a burlap bag inside a fiber-glass tank (see figure 5). The liquids seep through the bag and into tank 1. When tank 1 is full it overflows into tank 2. The sun heats air behind the two separate chambers covered with glazing. When the air in the lower solar chamber is warmed, an automatic damper opens. The thermosiphon action pulls the warmed air through the waste storage areas, as the arrows show in figure 6, which evaporates the liquids. The warm air flows first through the liquid tanks and then around and through the solids in the burlap bag before exiting through the vents at the top of the upper solar chamber. Calculations show that approximately 25 percent of the solar energy striking the glazing evaporates liquid.

TEST

A 55-gallon drum of waste that would have been flown out by helicopter was dumped into one of the empty toilets. The weather during the September test was calm and sunny with the exception of a few overcast days. All free liquid was gone within 30 days, and the overall weight reduction of the sewage was 90 percent in 35 days.

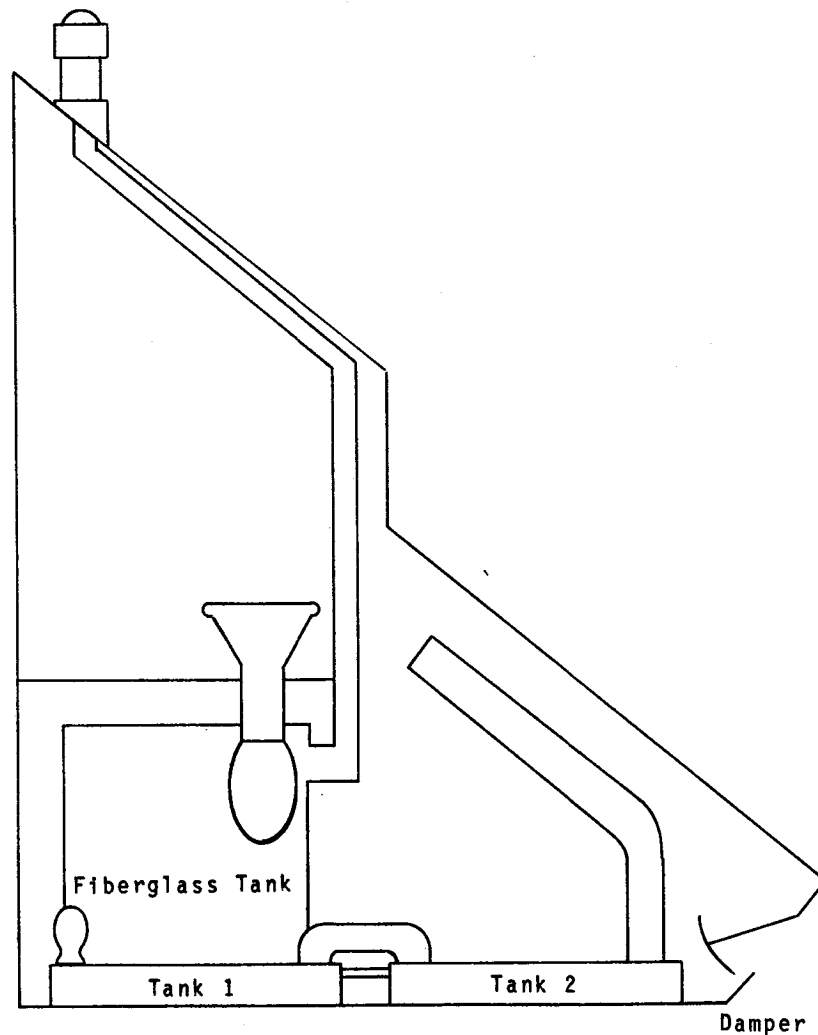


Figure 5.--Side view diagram of solar toilet.

At the end of the test, the solids on the outer edge of the bag (see figures 7 and 8) were in a semipliable fibrous state while the interior solids were still moist. All the solids were dry enough to be carried out on packstock without danger of leakage. Toilet performance during the 1986 season under full use conditions confirms the test results.

MAINTENANCE

A wilderness ranger handles whatever maintenance is needed. According to the Wilderness Area Manager,

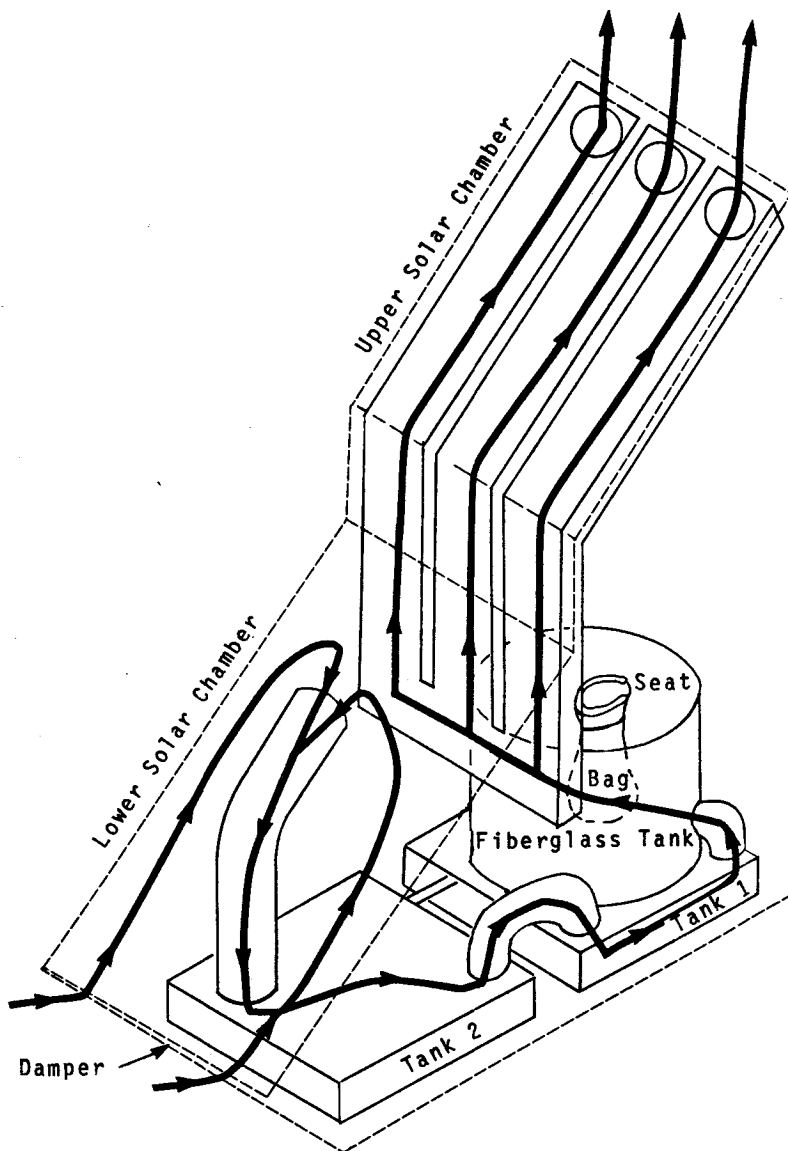


Figure 6.--Diagram of air flow through solar toilet.

one individual can handle the processed storage bags, which can be packed out.

COSTS

The average installed cost per unit for this 2-unit installation was a little more than \$20,000.

Fiberglass tanks, ducting, and
toilets

\$13,000

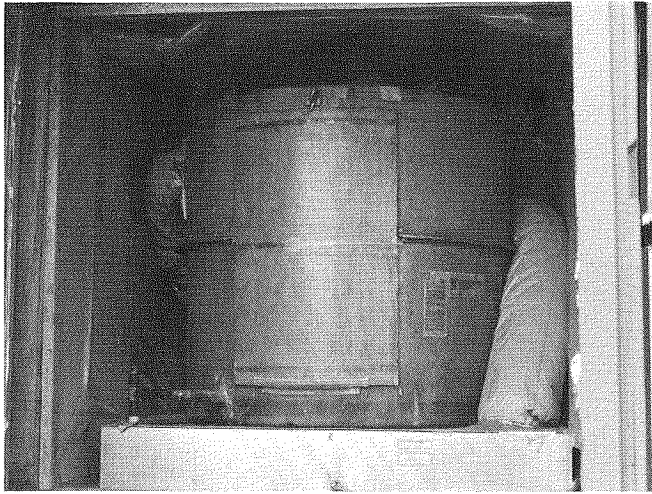


Figure 7.--Fiberglass tank.

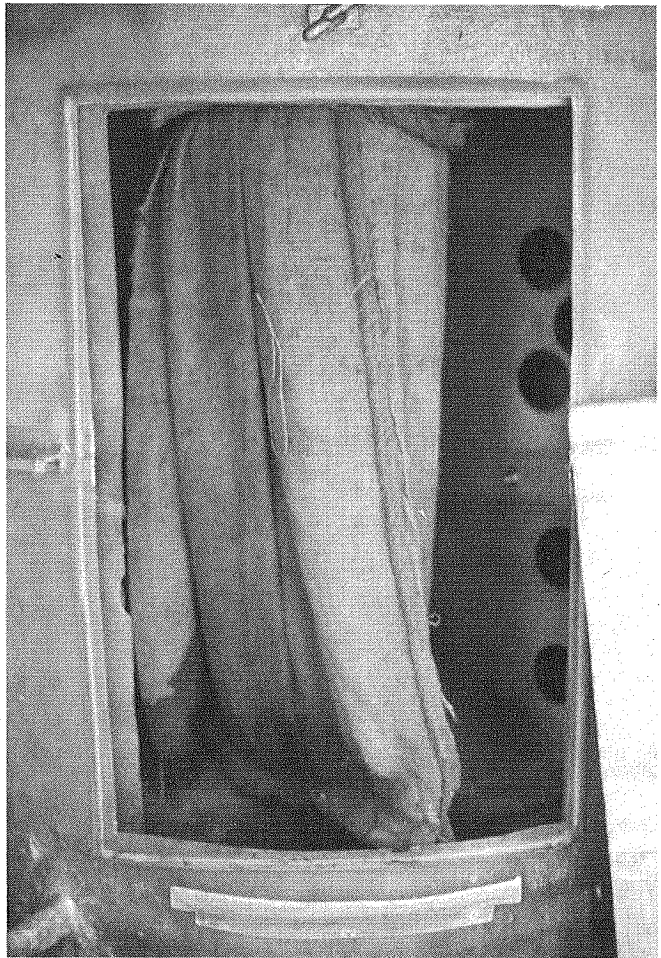


Figure 8.--View of gunny sack through tank cleanout port.

Design (structural modifications for snow and wind load)	\$1,500
Toilet construction (materials and labor, other than above)	\$27,000
Helicopter transport of toilets to site (performed by test pilots at no cost to the Forest Service)	\$0

POSSIBLE FUTURE DIRECTIONS

Possibilities for the future include the design of a componentized, light-weight toilet with the above concepts to give maximum mobility while serving sanitation needs in remote areas and the design of a toilet with the dehydration/thermosiphon concepts for developed recreation sites where vault pumping is expensive or difficult.

**FOR MORE
INFORMATION**

For additional information, please feel free to contact the authors at the following telephone numbers:

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Dave McCauley (415) 825-9800

The following two articles were prepared by Forest Service employees enrolled in a 2-year master's program at Oregon State University (OSU):

"An Empirical Evaluation of Network Analysis Models Used by the Forest Service"

"Skyline Thinning Cost Comparison for Three Yarding Systems"

The Washington Office Timber Management and Engineering Staffs have sponsored this graduate-level training at OSU for several years. The OSU program affords enrollees the option of specializing in either Transportation for Resource Management or in Logging Engineering. Beginning in 1986, we asked the Forest Service OSU students to submit a paper from their master's projects for publication in Engineering Field Notes so that others could become more aware of the benefits the Forest Service derives from sponsoring the program.

An Empirical Evaluation of Network Analysis Models Used by the Forest Service

*Thomas L. Moore
Transportation Engineering Program
Oregon State University*

BACKGROUND

Computer programs have been used to solve network analysis problems in forestry applications since the early 1970's. These programs were developed to identify the least costly transportation system to serve an area guided by land management objectives. The Forest Service frequently uses several computer programs to solve for the least cost road development network in a planning area.

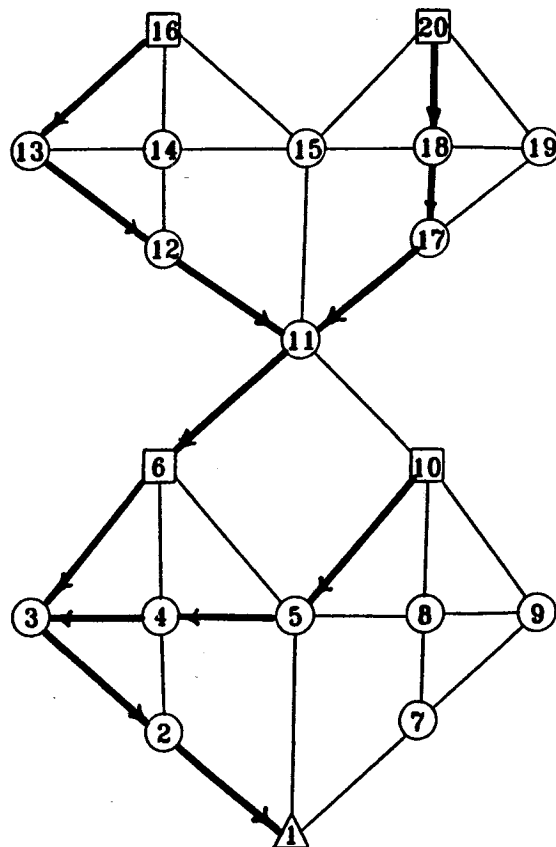
MINCOST and the TIMBER TRANSPORT MODEL were the first programs used. Other programs, such as TRANS, NETWORK, and the INTEGRATED RESOURCE PLANNING MODEL/TRANSHIP (IRPM), were developed later to solve similar problems. Studies to determine the accuracy of these models in obtaining the optimal solution were not initiated until the early 1980's. The first evaluations were experimental in nature and were performed on the MINCOST and TIMBER TRANSPORT models. Wong (1) evaluated several small problems to determine how the MINCOST model would perform. Wong observed that the MINCOST model arrived at the optimal solution on only three of the eight networks he tested. He recorded errors as much as 48 percent above the optimal solution. Kirby (2) focused on evaluating the TIMBER TRANSPORT model. His example (figures 1 and 2), also experimental in nature, demonstrates the inaccuracies of the model. The TIMBER TRANSPORT model provides a solution that is 620 percent higher than the TRANSHIP solution.

PURPOSE & SCOPE of STUDY

Only limited studies have focused on assessing the quality of solutions for larger problems typically used in field situations. This study addresses this question and represents the first published, large-scale evaluation of network models currently used in Forest applications.

The purpose of this study was to compare the solutions generated by three network models using data from five field problems currently evaluated in

LEGEND
 Origin Node □
 Demand Node △



T. Transport Solution

Haul Cost = \$329,000

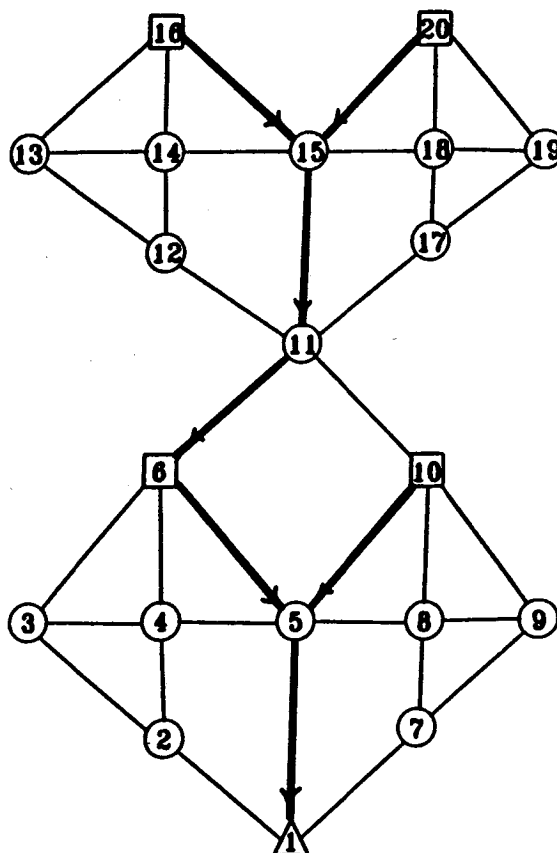
Fixed Cost = \$5,620,000

Total Cost = \$5,949,000

NOTE: All Sales 1,000 mbf.

Figure 1.--Kirby's TIMBER TRANSPORT MODEL example and TIMBER TRANSPORT MODEL solution.

LEGEND
 Origin Node □
 Demand Node △



Transshipment Solution

Haul Cost = \$560,000

Fixed Cost = \$400,000

Total Cost = \$960,000

NOTE: All Sales 1,000 mbf.

Figure 2.--Kirby's TIMBER TRANSPORT MODEL example and TRANSHIP solution.

Forest applications. The approach developed for this study was to assess the significance of the errors provided by the models compared to the uncertainty of the input data.

We have evaluated three network models: NETWORK, MINCOST, and the TIMBER TRANSPORT MODEL. The study was limited to solving the single time period problem with no more than 100 loading nodes and 99 project (fixed) costs.

STUDY AREAS

The study areas used for this research were selected with the objective of demonstrating how the models would perform using various network sizes, types, and complexities. All of the study areas previously were evaluated in the field using one of the network models. The data then were reformatted and run through the other two models.

The networks selected exhibit various degrees of connectivity ranging from basic tree patterns with few loops to grid-type networks with many loops.

The five study areas are located in different areas around the country, and this is partially the reason for the wide variation in the input data. For example, the Off Planning Area (figure 3), near Mt. St. Helens in Washington, incorporates logging system analysis, which increases variable costs. The Peavine Planning Area (figure 4) in California considers smaller sale units, thus providing for lower volumes. This network includes several three-node loops to determine whether the inaccuracies of the MINCOST model, as identified by Wong, also exist in field problems as well as in experimental applications. The Silver Planning Area (figure 5), situated in Idaho, represents the average of all the networks. The Kosciusko Planning Area (figure 6) is a small island located in Alaska. This network is unique in that it considers the cost of water transport. Logs are hauled via trucks to a terminal transfer site, barged to the mainland, loaded back onto trucks, and hauled to the destination. This water haul increases the average variable cost compared to the other networks. The Beaverdam Planning Area (figure 7) is located in Tennessee. Labor rates for construction projects are much less than in the west and therefore road construction costs are much less.

LEGEND
 Origin Node
 Demand Node
 Fixed Costs ----

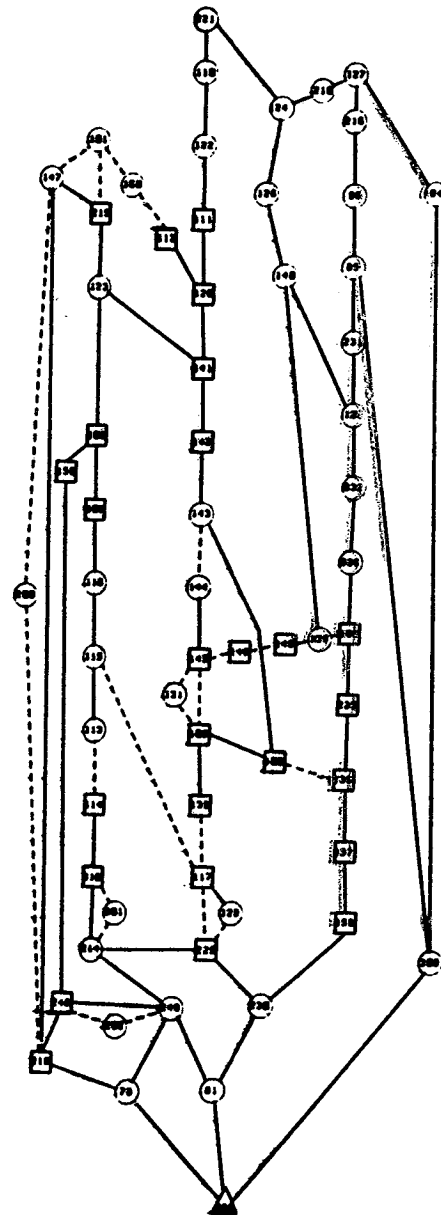


Figure 3.--Off Planning Area coded network.

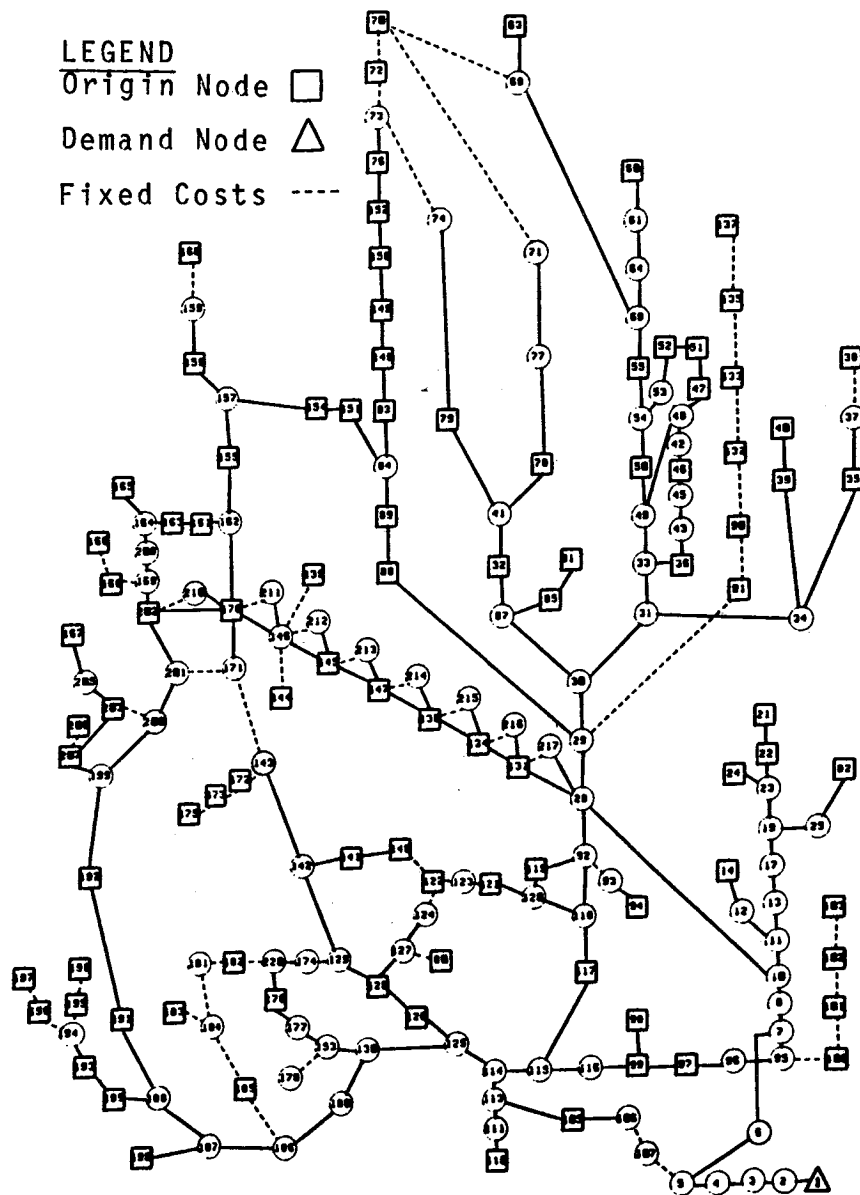


Figure 4.--Peavine Planning Area coded network.

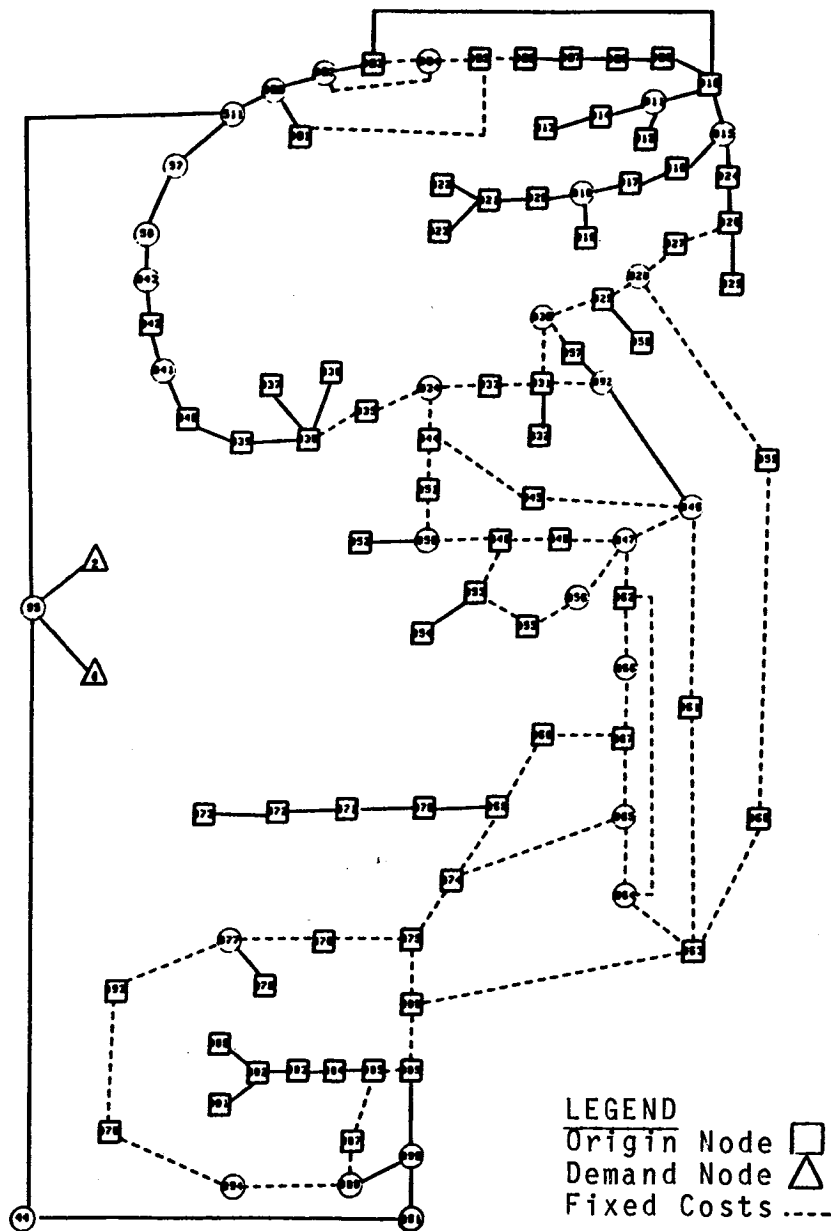


Figure 5.--Silver Planning Area coded network.

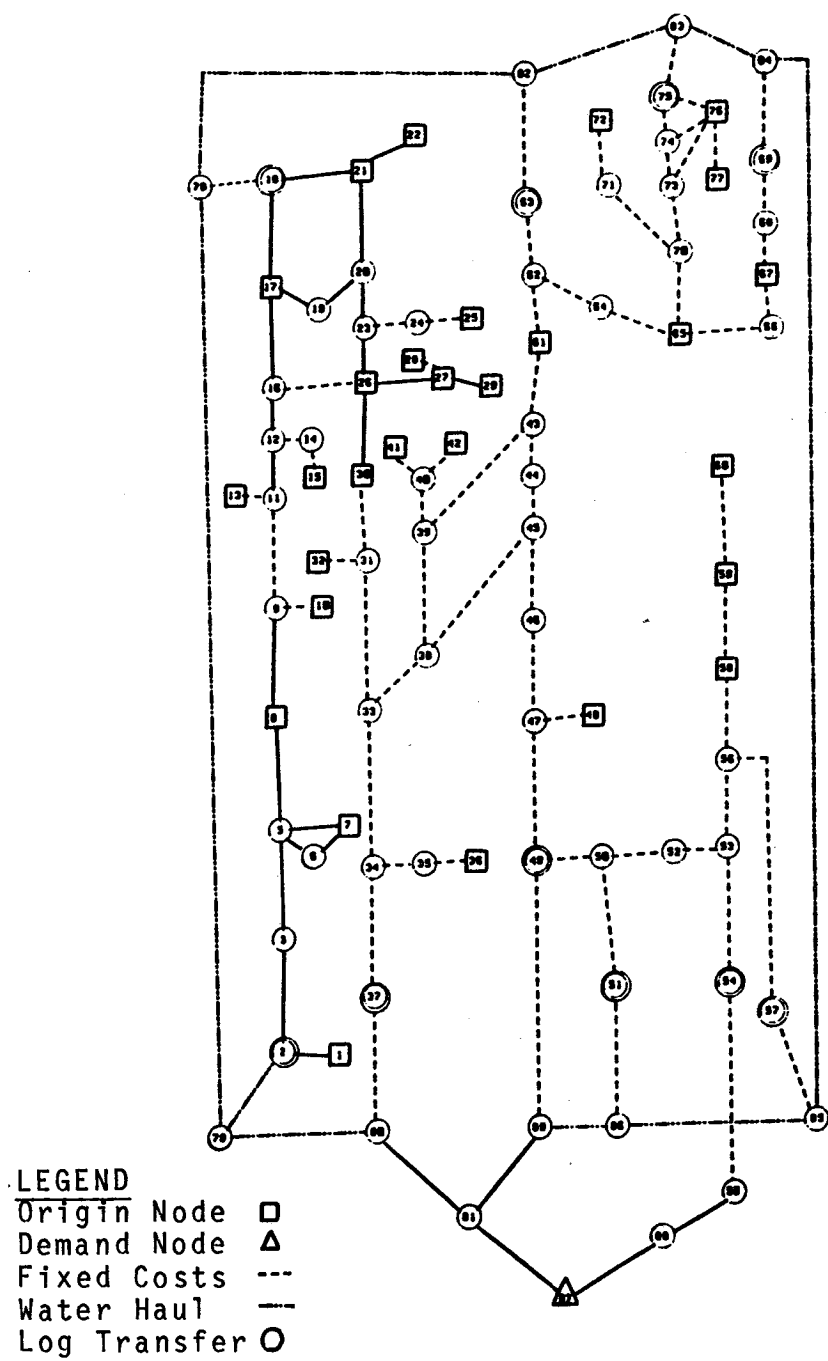


Figure 6.--Kosciusko Planning Area coded network.

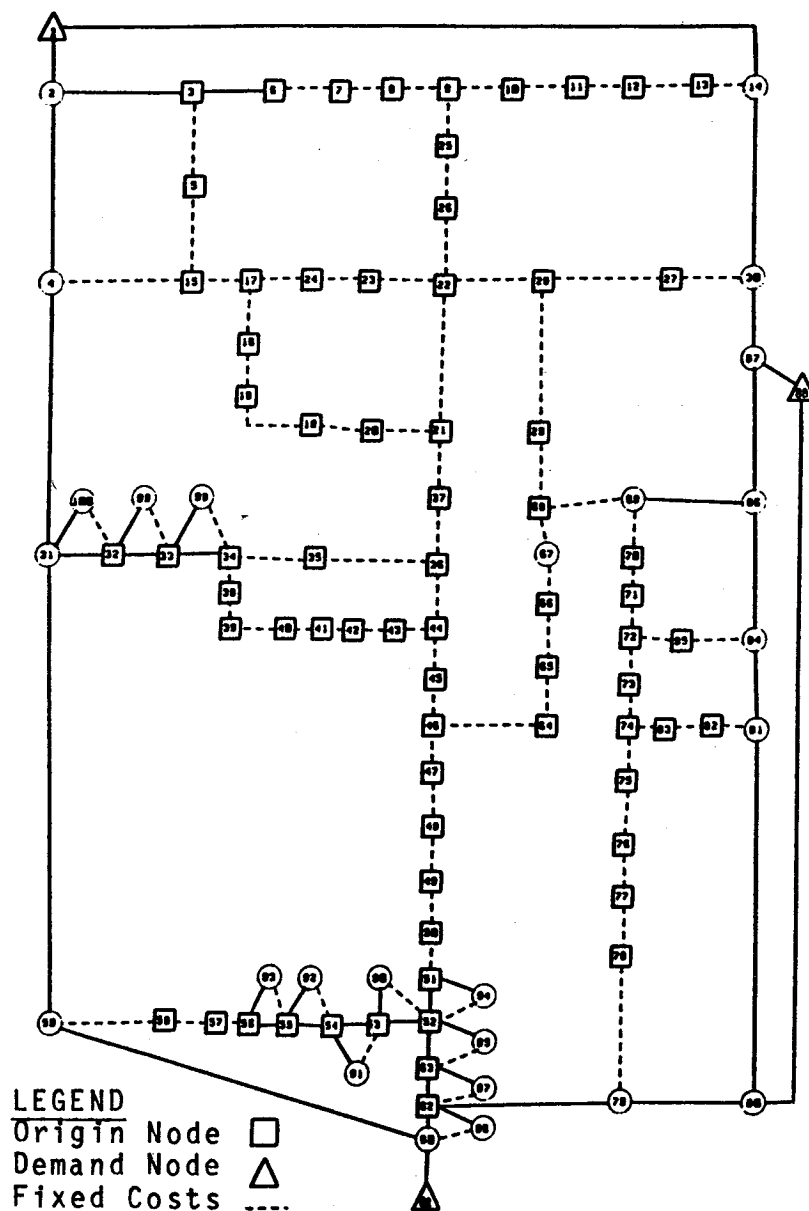


Figure 7.--Beaverdam Planning Area coded network.

PRELIMINARY ANALYSIS RESULTS

The five study areas were analyzed using the three different network models. The MINCOST and NETWORK models ran smoothly and yielded solutions relatively quickly. The TIMBER TRANSPORT model presented many difficulties. The five networks were run through Phase 1, the route generation phase, successfully. The results from these runs then were loaded into Phase 2, the optimization phase, using the "O" option, and resulted in the program aborting on four of the five planning areas. The Off Planning Area was the only network that ran successfully. Upon further investigation of the other four, it was found that the mixed-integer linear program, a program used by TIMBER TRANSPORT, was too small to evaluate these larger network problems. The program was not completing the branch and bound technique to arrive at the linear program optimal solution. The four areas subsequently were run using the "F" option and produced an answer.

Two versions of NETWORK were included in this analysis. Version 9 is the most current and provides a better answer for one of the networks.

The results of running the networks using the three different models are shown in table 1. These solutions were obtained without user intervention and without incorporating manual sensitivity analysis.

NETWORK SENSITIVITY to INPUT DATA

In the second half of this project, we developed a procedure to compare the errors provided by the network models to uncertainties of the input data.

Planners cannot consistently estimate every road cost, haul cost, and timber unit volume exactly; some degree of uncertainty is associated with every estimate. Generally, if this estimate is within 10 to 20 percent from the true value, the analysis is deemed satisfactory. It is largely unknown whether the errors in the network model outweigh the errors from using uncertain data.

This project addressed this question by employing a technique termed "Monte Carlo simulation." Each value in the link and sale file was changed to conform to a certain distribution. Adjusting every value exactly 10 to 20 percent from the estimate and then running the network model is one approach. However, this method would not represent what occurs in the field. In reality, some of the values may be estimated exactly while others could be very far

Table 1.--Summary of initial run results

Planning Area	Total Cost (dollars)					Percent Increase Over Best Solution				
	NETWORK (Ver. 8)	NETWORK (Ver. 9)	MINCOST	TTM (F-Option)	TTM (O-Option)	NETWORK (Ver. 8)	NETWORK (Ver. 9)	MINCOST	TTM (F-Option)	TTM (O-Option)
Off	3,612,804	3,612,804	3,658,155	NA	4,738,935	0	0	1.3	NA	31.2
Peavine	1,459,524	1,459,524	1,474,166	NA	NA	0	0	1.0	NA	NA
Silver	4,384,842	4,384,842	4,532,140	4,868,373	NA	0	0	3.4	11.0	NA
Kosciusko	17,622,233	17,622,233	17,622,233	18,395,092	NA	0	0	0	4.4	NA
Beaverdam	418,776	389,768	400,150	454,663	NA	7.4	0	2.7	16.7	NA

Table 2.--Sensitivity and uncertainty values.

Planning Areas	NETWORK (Ver. 8)	NETWORK (Ver. 9)	MINCOST	TTM (F-Option)	TTM (O-Option)	Uncertainty Value ^a	Sensitivity Value ^b	Maxsim Value ^c
Off	0	0	1.3	NA	31.2	0.49	76.0	76.0
Peavine	0	0	1.0	NA	NA	0.12	47.0	47.0
Silver	0	0	3.4	11.0	NA	1.14	1.0	2.0
Kosciusko	0	0	0	4.4	NA	0.57	48.0	48.0
Beaverdam	7.4	0	2.7	16.7	NA	2.63	1.0	2.0

^aUncertainty Value = $\frac{\text{Expected Value of 100 Scenarios}}{\text{Original Network Solution Cost}} - 1 \times 100$

^bSensitivity Value = $\frac{\text{Number of Scenarios with Original Solution}}{100 \text{ Scenarios}} \times 100$

^cMaxsim Value = $\frac{\text{Maximum Number of Scenarios with Identical Results}}{100 \text{ Scenarios}} \times 100$

off. Indeed, if a detailed study were to monitor the actual values relative to the estimated values, a certain distribution would exist. Because a study of this nature would require a great deal of information, the normal distribution is assumed for this analysis.

Each value in the link and sale file of a network model was changed to conform to the normal distribution using the following limits:

- (1) Fixed Costs. Fixed costs (road construction costs) were allowed to fluctuate ± 20 percent from the estimate for one standard deviation or 67 percent of the occurrences.
- (2) Variable Costs. The Forest Service does not monitor log hauling costs since it is an item in the timber sale appraisal and not subject to individual bidding. Although a variation exists for every cost, this report does not consider this variation.
- (3) Timber Volumes. Timber volumes generally experience the greatest variation. It is reasonable to expect that timber volumes could fluctuate ± 30 percent for one standard deviation.

Using different random normal numbers, 100 simulations were generated. The results were analyzed to determine how many solutions were identical to the original. A large number of solutions that duplicated the original would indicate that the particular network was not sensitive to changes in the input data.

Two important values were generated from the results of these simulations. The "Sensitivity Value" represents the number of times that the original network solution was encountered, expressed as a percent of the number of simulations run. The "Uncertainty Value" was determined by fixing the solution paths generated by each of the 100 simulations and injecting the original network data into this fixed set of paths. The solution cost was recalculated for each of these simulations, and the expected value then was determined from these 100 simulations. This value was represented as a percent increase above the original network solution cost and called the Uncertainty Value. The Uncertainty Value was compared to the errors

produced in the models and a determination was made addressing the significance of these errors relative to the uncertainty of the data.

RESULTS & DISCUSSION

The above procedure was performed on all five planning areas by running 100 simulations for each area. The results are shown in tables 2 and 3. Table 2 reveals that the Uncertainty Value is always less than the errors produced by the models. For example, the MINCOST model produced an error of 1.3 percent above the solution provided by NETWORK for the Off Planning Area. The increase resulting from uncertainty for this study area is 0.49 percent. This would tend to indicate that the errors produced by the models outweigh the errors produced by using uncertain data. Basic statistical theory can be used to determine the level of significance of these errors. Table 3 identifies the confidence levels for each of the planning areas using the various network models. This table shows that most of the errors produced by the models are significant. Two areas using the MINCOST model, Off and Beaverdam Planning Areas, developed levels of significance of 0 percent, indicating that the uncertainty of the data may be more important than the errors developed by the MINCOST model.

CONCLUSIONS

The NETWORK (Version 9) program provided the lowest cost solutions to all five planning areas. TIMBER TRANSPORT generated the highest cost answers and MINCOST provided solutions that generally were slightly higher than the optimal.

The TIMBER TRANSPORT "F" option consistently provided inferior results and should be avoided. The TIMBER TRANSPORT "O" option worked well for smaller problems with few projects and loading nodes and having less than 10 paths to the destination per each loading node. Larger problems cannot be solved using the "O" option because of the limitations of the mixed-integer linear program used by TIMBER TRANSPORT.

The MINCOST model had difficulty solving the three-node loop problems nested in field-sized networks as well as in experimental examples previously demonstrated by Wong.

The analysis of the five planning areas evaluated in this report shows that the errors provided by the network models generally are more significant than the errors from uncertain input data. The exceptions

Table 3.--Percent confidence levels of significance for uncertainty.

Planning Areas	NETWORK (Ver. 8)	NETWORK (Ver. 9)	MINCOST	TTM (F-Option)	TTM (O-Option)
Off	NA	NA	0	NA	99.9
Peavine	NA	NA	92.9	NA	NA
Silver	NA	NA	97.1	99.6	NA
Kosciusko	NA	NA	NA	97.1	NA
Beaverdam	88.8	NA	0	98.7	NA

to this statement are the Off and Beaverdam Planning Areas, which provided levels of significance of 0 percent using the MINCOST model.

This study would tend to indicate that the selection of a network model should be based partially on the accuracy of solution sought.

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Skyline Thinning Cost Comparison for Three Yarding Systems

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ABSTRACT

Yarding costs and production rates of prebunching with a small yarder and swinging with a midsize yarder are compared to conventional yarding with the small and midsize yarders in two different thinning intensities.¹ For the average study conditions, conventional yarding with the small yarder cost 9 to 12 percent less than conventional yarding with the midsize yarder. Conventional yarding with the midsize yarder and prebunch and swing yarding had similar costs. The cost of conventional yarding was 20 to 22 percent higher in the light thinning compared to a heavy thinning. This increase in cost would be less for the small yarder when more favorable manual slackpulling conditions exist. Cost reductions are possible for prebunch and swing yarding by using a smaller crew, yarding on steeper slopes, and using different yarding techniques. With these changes, prebunch and swing yarding could become less expensive than conventional yarding with a small or midsize yarder.

INTRODUCTION

As more second-growth stands require harvesting, the forest industry will need to find ways to reduce the cost of harvesting these stands. Beuter (1980) indicated that in western Oregon 70 percent by volume of the softwood timber is less than 21 inches in diameter at breast height (dbh), with 37 percent less than 13 inches dbh. Average stand diameters of 10 to 20 inches will be common as more of these stands are clearcut or thinned. These changes require more efficient ways to handle the increased

¹Logging was conducted by More Logs, Inc., Sweet Home, Oregon.

number of small pieces, such as using smaller, less expensive equipment or different techniques to increase production.

Prebunch and swing yarding has been considered as a harvesting procedure to use midsize yarders more efficiently in thinnings (Kellogg, 1980). In this technique, a small yarder brings logs to the skyline corridor. After work is completed with the small yarder, a midsize yarder yards prebunched logs to the landing. The advantages of the procedure are that the small, lower-cost yarder is used for the more time-consuming portion of yarding while the midsize yarder can obtain optimal payloads and work at faster yarding speeds. Thus, the capabilities of each machine are realized more fully.

Past smallwood skyline harvest studies at Oregon State University have quantified production rates and costs for different yarders and thinning operations. These studies generally have shown the advantage of smaller, less expensive equipment (Kellogg, 1983; Kellogg and Olsen, 1984). Kellogg (1976) and Zielinsky (1980) found that prebunch and swing yarding produced a significant savings compared to conventional yarding² with a midsize yarder, while Keller (1979) observed a significant increase in yarding costs for prebunch and swing yarding.

LeDoux and Butler (1982) used simulation to study the cost of conventional yarding versus prebunch and swing yarding for a range of diameter classes and stem removals. Simulation results showed that, for the entire range of stem removals and diameter classes studied, prebunch and swing yarding produced considerable savings over conventional yarding with a midsize yarder. Thinning intensity did not significantly influence either conventional yarding or prebunch and swing costs when tree removal was more than 80 stems per acre. However, increased log size significantly improved productivity and reduced costs.

The purpose of this study was to compare harvesting production and cost between three different yarding

²Conventional yarding in a thinning involves yarding logs to a skyline corridor and then yarding the logs to the landing in one complete cycle.

techniques in two thinning intensities. Regression analysis was used to relate stand and harvesting variables to the production and cost of each yarding condition.

STUDY SITE & METHODS

The study area was located in the Cascade Mountains east of Salem, Oregon, on the Willamette National Forest. The main merchantable species was Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), with western hemlock (Tsuga heterophylla (Raf.) sarg.) and noble fir (Abies procera (Rehd.)) accounting for only 5.5 percent of the volume. The understory was mostly vine maple (Acer circinatum (Pursh)) and rhododendron (Rhododendron macrophyllum (D. Don)).

The study area averaged 49.8 cunits (21.5 thousand board feet (mbf)) per acre in about 350 trees per acre. The average diameter at breast height for the study area was 12.2 inches. The heavy thinning removed 125 trees or 25.2 cunits (10.9 mbf) per acre while the light thinning removed 80 trees or 12.0 cunits (5.2 mbf) per acre. Volumes do not include crop trees removed because of damage or yarding requirements.

The small yarder was a Koller K-300 (figure 1) equipped with a Koller multispan, manual slack-pulling carriage. The Koller K-300 has a tower height of 23 feet, external yarding distance capabilities of 1,000 feet and a 60-horsepower rating. This machine was used for conventional yarding and prebunching. A loader was required for all the conventional Koller yarding because of steep landing chutes or deck size. An experienced five-person crew, consisting of a rigging slinger/hooktender, two choker setters, a yarder engineer/chaser, and a loader operator, work during the conventional yarding. The loader operator was not needed during prebunch yarding. Chokers were preset with an average of three chokers used per turn.

The midsize yarder was a Madill 071 crawler-mounted, mobile skyline yarder equipped with a Danebo MSP mechanical slackpulling carriage (figure 2). The Madill 071 has a tower height of 50 feet, an external yarding distance of 1,800 feet and a 284-horsepower rating. This machine was used for conventional yarding and swing yarding. Decking and loading were accomplished using a Bantam C-366 hydraulic heel boom loader. An experienced crew consisting of a hooktender, a rigging slinger, two choker setters, a



Figure 1.--Koller K-300 yarder.

chaser, a yarder engineer, a loader operator, and the company owner were used during conventional and swing yarding. For conventional yarding, chokers were preset with an average of four chokers used per turn. Four chokers also were used during swing yarding, but they were not preset because the prebunched logs were located under the skyline. During swing yarding, usually two or more logs were yarded per choker.

PRODUCTION RATES & COSTS

Hourly operating costs for yarding and loading operations were \$284.50 for the Madill yarder, \$123.00 for the Koller yarder, and \$94.04 for prebunch yarding (Hochrein, 1986). Table 1 summarizes yarding production and cost per cunit. Log value was \$95.04 per cunit, and other harvesting

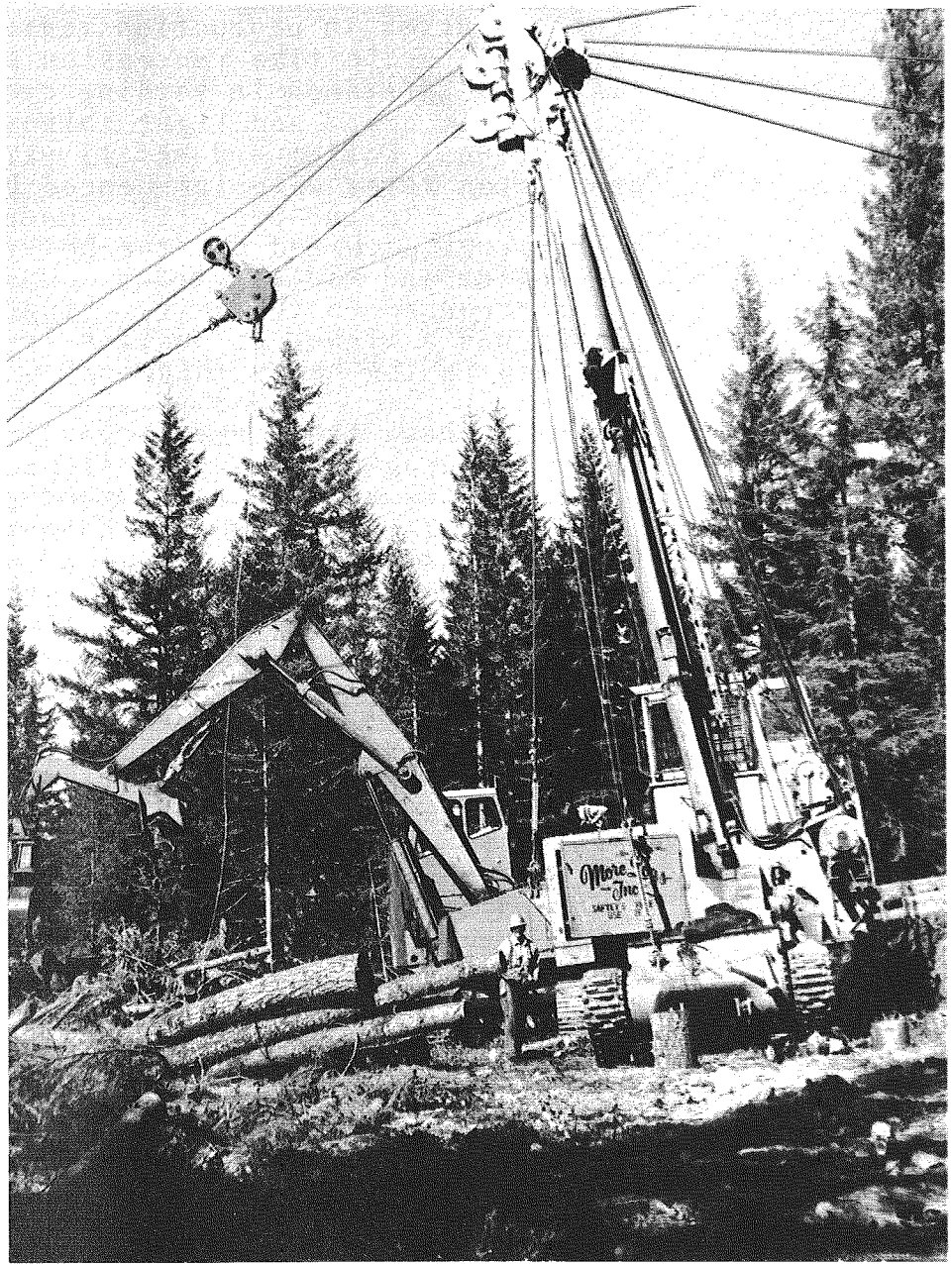


Figure 2.--Madill 071 yarder.

costs for the Koller were, respectively, 12 percent and 9 percent lower than the Madill in the heavy and light thinning. The cost of prebunch and swing yarding was similar to the Madill yarding even though swing yarding had a 67 percent increase in production compared to conventional Madill yarding.

Table 2 shows delay-free yarding cycle regression models. The thinning condition indicator variable (cut) occurred in production regression models but not in the cycle time regression models. No significant difference in yarding cycle times occurred between the heavy and light thinning levels for the conventional Koller and Madill yarders. In contrast, production rates were influenced by the thinning condition. In the production models, a negative coefficient occurred for the heavy thinning for both the Koller and Madill yarder. However, larger turn sizes occurred in the heavy thinning, so the net result was a higher production level for both machines in the heavy thinning.

DISCUSSION

Figure 3 shows the range of yarding costs for the light thinning when varying slope yarding distance while holding the other independent variables constant. Yarding with the Koller yarder is the least expensive for the range of yarding distances shown. However, with increased slope yarding distance, the savings between the Koller and Madill becomes smaller.

Production was 20 to 22 percent lower in the light thinning for both machines compared with the heavy thinning, in part because of the increased landing and road changes required for the light thinning levels, the smaller turn size, and some adverse yarding conditions. The effective hour decreased 7 percent and 11 percent for the Koller and Madill respectively in the light thinning. Turn size decreased 17 percent for the Koller and 23 percent for the Madill in the light thinning. Flat chord slopes and high ground-to-carriage clearance also contributed to decreased production in the light thinning for the Koller.

The average chord slope in one portion of the light thinning was 15 percent compared to 57 percent in the heavy thinning. With increased slope yarding distance, pulling line laterally became harder because of greater friction between the line and the ground. In another portion of the light thinning, as the slope yarding distance increased, the carriage height also increased to more than 120 feet. As the carriage height increased, the amount of sag in the mainline also increased, and additional yarding time was required to take this sag out of the mainline.

Table 1.--Harvest production and cost.

	Heavy Thinning		Light Thinning		
	Koller Yarder	Madill Yarder	Koller Yarder	Madill Yarder	Prebunch Swing
Delay-free production (cunits/hour)	3.57	7.15	3.12	6.60	5.06/10.61
Effective hour (percent)	73	74	68	66	71/69
Actual production (cunits/hour)	2.59	5.27	2.13	4.38	3.64/7.33
Yarding and loading (\$/cunit)	47.46	54.00	57.88	64.97	64.65
Total logging cost (\$/cunit)	76.70	83.24	87.12	94.21	93.89
Profit (\$/cunit)	18.34	11.80	7.92	0.83	1.15
\$/MBF = \$/cunit times 2.315)					

Table 2.--Delay-free yarding regression models.^a

Dependent Variable	Intercept	Slope Distance ^b (feet)	Lateral Distance (feet)	Number of Logs	Slope (percent)	Indicator Variable ^c	R ^{2d}
Production (cubic foot/hour)							
Koller yarder	197.4	-0.2485	-0.8385	132.2		-52.60	0.68
Madill yarder	464.7	-0.3380	-1.885	130.5		-137.6	0.71
Prebunch	730.9	-0.3123	-2.008	136.8	-6.327		
Swing	554.5	-0.6681		140.2			0.62
Time/yarding cycle (minute)							
Koller yarder	3.587	0.003672	0.01657	0.2337	-0.1009		0.37
Madill yarder	1.838	0.003403	0.02360	0.1903			0.45
Prebunch	-1.206	0.002334	0.01057	0.6446	0.05662		0.63
Swing	2.936	0.003521		0.09862			0.26

^aAll values in the table are regression model coefficients.

^bAll variables are significant at the 0.05 level.

^c1 = heavy thinning and 0 = light thinning.

^dCoefficient of determination.

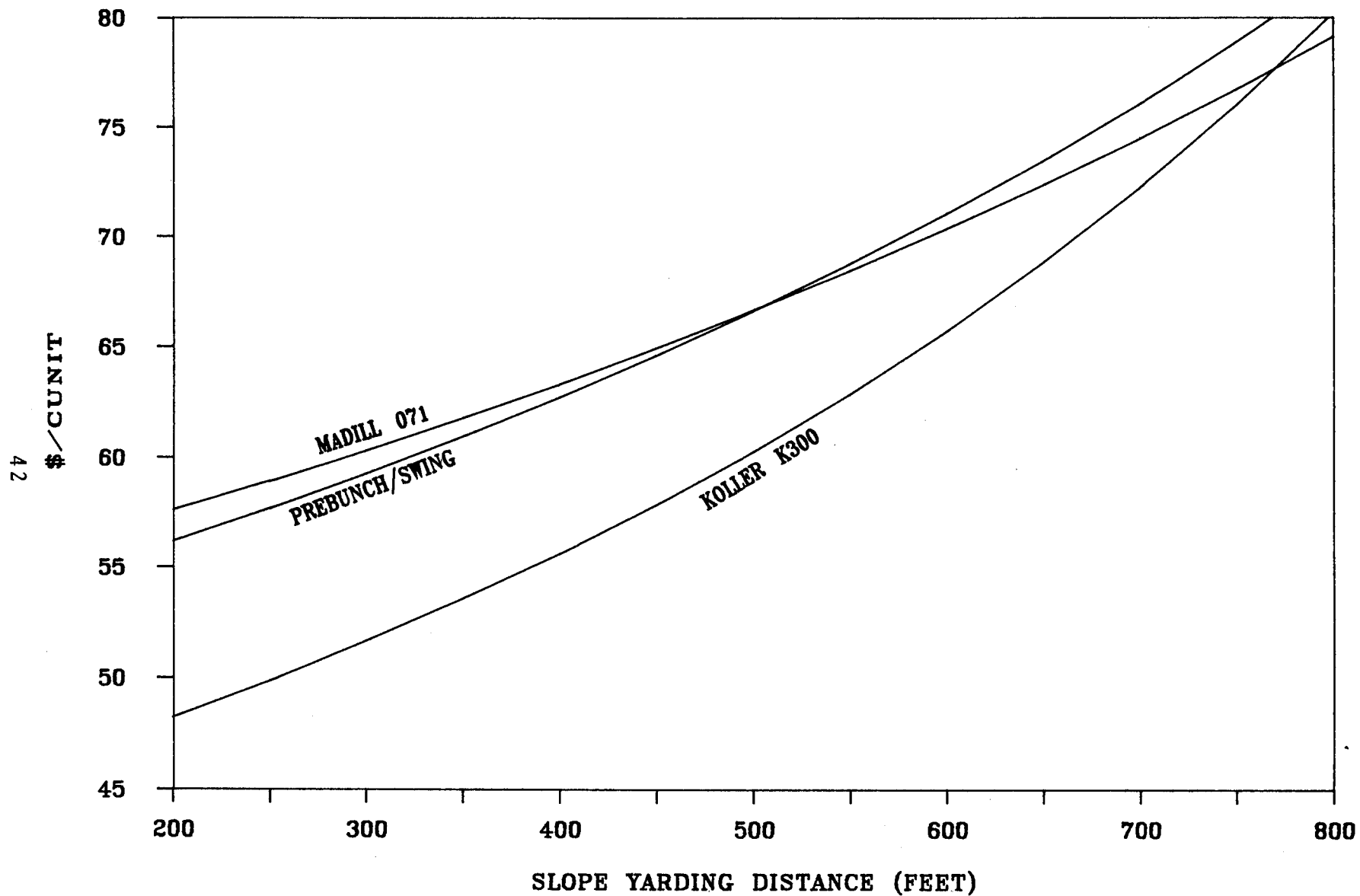


Figure 3.--Yarding and loading cost for light thinning when slope yarding distance is varied.

These conditions also occurred in portions of the light thinning with the Madill yarder, but they did not significantly influence production because of the mechanical slackpulling carriage. For the Koller in the light thinning, yarding time increased as the slope yarding distance increased because hand slackpulling is required for lateral yarding. Without these conditions, conventional Koller yarding in the light thinning would have had higher production and lower costs.

Although these yarding conditions affected conventional Koller yarding, they were much more significant during prebunch yarding. Slope yarding distances were greater for prebunching than Koller yarding in the light thinning. Also, the carriage was higher during prebunching because of headspar and tailhold locations. During prebunching, heavy slash present in some of the corridors contributed to greater line friction and increased the cycle time.

POTENTIAL IMPROVEMENTS

Important considerations in selecting areas to prebunch with a small yarder where slack is pulled manually include the chord slope and the carriage height. Areas with flat chord slopes and much understory vegetation should be avoided. For areas with more than 50 feet between the ground and skyline, keep the skyline close to the ground to avoid excessive sag in the mainline, possibly by placing a "pull-down block" anchor at the base of a tree to keep the skyline lower.

In areas where the difficulty of manual slackpulling is not influenced by slope yarding distance and the carriage is kept close to the ground, the slope yarding term in the prebunch regression model should drop out. The slope yarding distance term was excluded from the prebunch regression model to simulate ideal yarding conditions. Additional savings could result with a smaller crew size than used in this study and with reduced delays through better use of personnel (Hochrein 1986). Figure 4 shows the yarding and loading costs when using these optimal conditions and techniques during prebunch and swing yarding compared with conventional yarding. For the average study conditions, prebunch and swing yarding with the Madill yarder was 15 percent cheaper than conventional yarding. Also, at slope distances greater than 325 feet, prebunch and swing yarding cost less than yarding with the Koller yarder. At distances greater than 325 feet, the increased

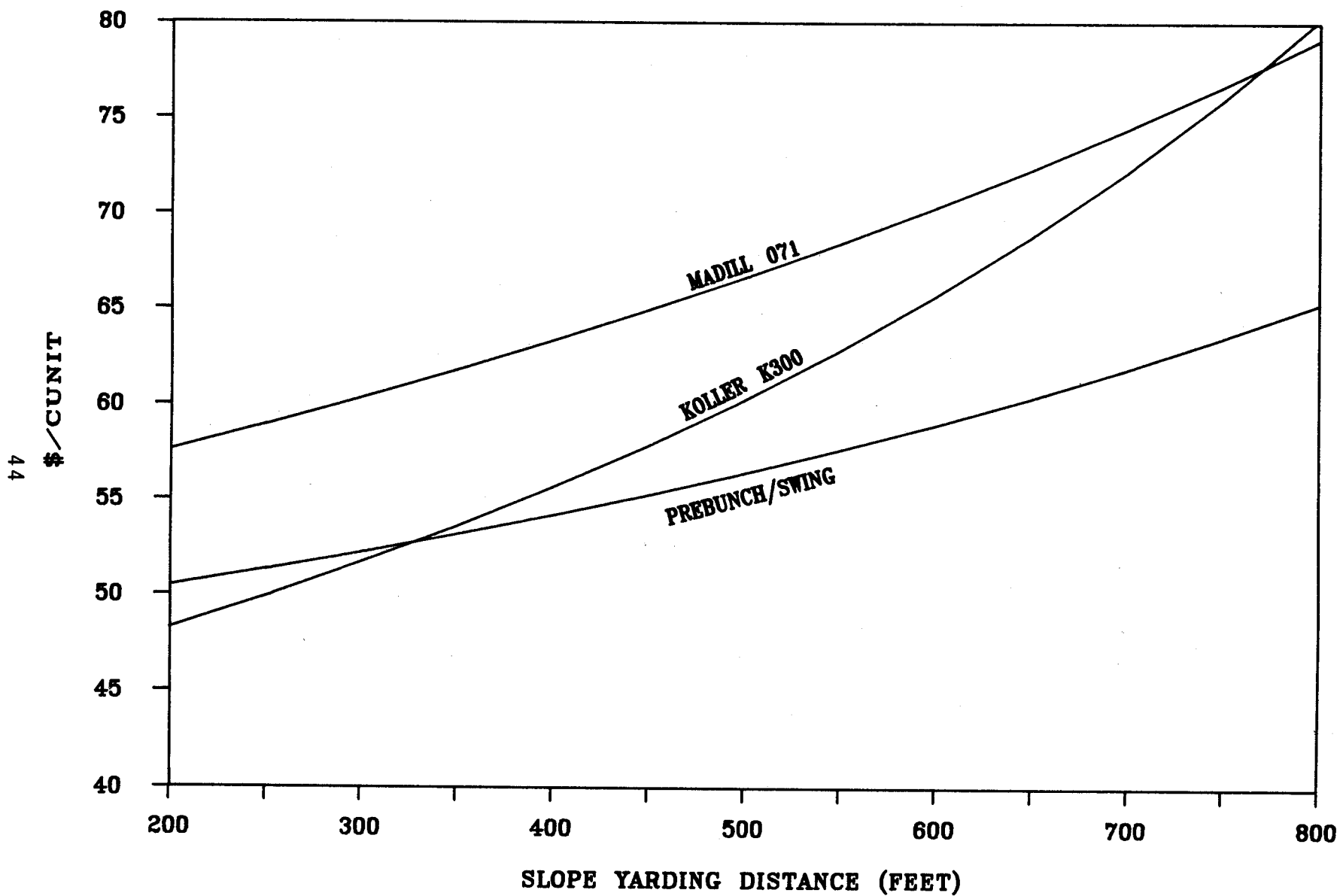


Figure 4.--Yarding and loading cost for prebunch and swing with optimal conditions and techniques compared with conventional yarding.

outhaul and inhaul speed plus larger turn sizes of the Madill yarder compensate for the additional handling involved in prebunch and swing yarding. At closer distances it seems better to yard conventionally with the Koller yarder and avoid the extra handling associated with prebunching.

CONCLUSIONS

Commercial thinning of stands on steep slopes with an average diameter at breast height of 12 inches and external slope yarding distances of less than 1,000 feet appear most economical to yard with a small yarder and small crew. The small yarder maintained a cost advantage in both the light and heavy thinning levels. While there is that cost difference, managers also should consider other variables, such as log size, yarding distance, and yarder availability, when selecting a yarder.

For the yarding conditions studied, the volume per acre removed had a significant effect on cost. Reducing the average number of trees removed from 125 to 80 increased the yarding and loading cost 20 to 22 percent. If manual slackpulling is not adversely affected by slope yarding distance, the increased cost of conventional Koller yarding would be somewhat less than the 20 percent observed.

Conventional yarding with a midsize yarder increased cost by 12 percent. Swing yarding production was significantly higher than production with the midsize yarder but did not lower costs below conventional midsize yarding for the operating conditions and techniques studied. Using a smaller crew size during prebunch and swing yarding and operating in areas where manual slackpulling is not adversely influenced by increased slope yarding distance appear to make prebunching and swinging less expensive than conventional yarding with either a small or midsize yarder.

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Errata Notice:

Please make the following editorial corrections to the "HP-41C Estimate of Uncertainty for Conventional Ground Method Closed Survey Traverses" article in your copy of Engineering Field Notes, Vol. 19, May-June 1987:

Page 51: In the 4th line from the bottom, " . . . 1-foot transit default" should read " . . . 1-minute transit default."

Page 54, figure 3 continued: On line numbers 316, 323, and 345, replace "X=Y?" with "X≠Y?"

If not corrected, the error in figure 3, page 54, could lead to erroneous program output.

Editor, EFN
6-9-87

HP-41C Estimate of Uncertainty for Conventional Ground Method Closed Survey Traverses

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Land Surveyor
Region 1*

INTRODUCTION

This program is based on a simplified, approximate method of analyzing propagated random errors in closed survey traverses to determine compliance with positional tolerance specifications. The analysis also will help to detect poor survey technique and the presence of blunders in the traverse. The program computes potential errors for each leg, an estimate of uncertainty of each station, and a closure, based on the methods used to perform the traverse. A sample analysis is included at the end of this documentation.

ANALYSIS CRITERIA

The analysis depends on four basic criteria: random error inherent in electronic distance measuring equipment, deviations of angle-measuring instruments resulting from reading and pointing error, foresight and backsight target miscentering, and distances traversed. Other random errors may exist but should be negligible when correct instrument adjustment and proper calibration procedures have been performed.

Poor statistical (expected) closures indicate imprecise methods. Problems to consider in such a case include backsight too short relative to foresight, poor methods of plumbing target, poor instrumentation, and too few angle repetitions.

Actual field closures poorer than expected are undesirable and should be examined for input errors or possible blunders in the traverse. Problems to consider in these cases include poorer technique than presumed in the tables, too large target size, too high horizontal and/or vertical angular rejection limit, improperly adjusted instruments.

Field closures better than expected are, of course, desirable and show better technique than presumed in the program or a more favorable propagation of random errors.

PROGRAM ANALYSIS

E_u is the estimate of uncertainty of position of each station relative to the point of beginning. The square root of the difference between E_u^2 for any given corner (or point) and E_u^2 of its controlling corner(s) should be less than the positional tolerance specified for the given corner.

Compute linear and angular closures before executing this program. Closing E_u will be compared to linear closure after proper angular adjustments have been made. If angular closure is significantly greater than expected, comparing E_u to linear closure will be misleading.

This is a stand-alone program. Although it can handle extremely long traverses, such cases might be analyzed better with a program integrated with traverse and least squares adjustment routines.

See figure 1 for the steps the program takes. Angle measuring and target plumbing errors are optional for each leg of each traverse. Initial values, input from tables 1 and 2 (in figure 1) in steps 3 and 4, become default values, and remain the default values regardless of optional values input for individual legs of the traverse. Distance measuring instrument coefficients are not optional.

Don't be discouraged by the speed of the program at the first station; things will speed up after the program has completed one run. For each station, the program will take between 15 and 40 seconds to input values, calculate results (figure 2), and print the analysis.

Table 1 is based on statistical data for instruments of European manufacture. The data are for one D-R pair of angles (two repetitions). The program is set up to handle data in this form. Tests have shown that some instruments have a standard deviation (s) greater than their least count. If the standard deviation of the instrument being used is available, use 3(s) rather than the value from table 1. If the standard deviation is not available, determine it. The best value to use is a value measured under the actual conditions in which the instrument is used, not the value measured under laboratory conditions. Use table 1 values in the interim.

Table 2 contains typical 3(s) values, based on measured centering errors of forced centering (leapfrogging tribrachs), independent tripod setups,

If printer is attached set to MAN SIZE : 024

Step	Label ^a	Instructions	Input	Key	Display
		In user mode, load program.			
1	A	Initializes the program.			LABEL
2		Prompts for printout label (if printer attached).	12 char.	R/S	ESTIMATE OF UNCERTAINTY DEFAULTS 3S, TABLE 1
3		Prompts permanent default value from table 1.	3s (SS.s)	R/S	3S, TABLE 2
4		Prompts permanent default value from table 2.	3s (Ft)	R/S	EDM/MM/COR
5		Prompts correction value from manufacturer (typically 5).	mm	R/S	EDM/PPM/COR
6		Prompts correction value from manufacturer (typically 5).	ppm	R/S	DIST. REPS.
7		Prompts for default, number of times distance is measured.	#	R/S	< REPS.
8		Prompts for default, number of single angle repetitions.	#	R/S	CLOSING DIST
9	(a)	Closing distance from prior calculation.	Ft.	R/S	< CLSRE
10		Angular error from prior calculations.	D.MMSS	R/S	BS DIST.
11		Initial BS distance (approximate).	Ft.	R/S	
12		Displays station number. Displays estimate of uncertainty of position of station.			STA = # EU = # HOR. DIST.
		Prompts horizontal distance to FS at each station.	Ft. 0 = end	R/S	DEFAULT Y, N
13	(*)	To (D)efault values for station (will skip steps 14 to 18) or to (E)nter optional values.		D E	DIST. REPS.
14		Enter number of distance repetitions if different than default.	#	R/S	3S, TARGET BS
15		Enter value from table 2 if different than default.		R/S	3S, TARGET FS
16		Enter value from table 2 if different than default.		R/S	3S, Table 1
17		Enter value from table 1 if different than default.		R/S	< REPS.

Figure 1.--Program steps.

Step	Label ^a	Instructions	Input	Key	Display
18		Enter number of single angle repetitions if different than default.		R/S	
		Displays potential error at each station. Angular error. Position error from angle. Position error from distance.		R/S	***ERROR POTENTIAL** <ERROR - DEG =D.MMSS <ERROR - FT. = Ft. DIST. ERROR = Ft.
	(C)	Cycles to step 12 until end.			
		Displays distance traversed.			DISTANCE = #
		Displays closure based on methods of survey. Closing distance. Angular closure.		R/S	STATISTICAL CLOSURE 1: Value EU = Ft. ER < = D.MMSS
		Displays closure based on survey data returned. Closing distance. Angular closure.		R/S	FIELD CLOSURE 1: Value ER LNR = Ft. ER < = D.MMSS
		End of program queue.			NOW WHAT?

^aLabel definitions:

- (a) May be used to restart at step 9.
- (B) May be used to back up one station to correct input.
- (C) May be used to review or reprint closures.
- (*) Flag 01 may be set for automatic default of stations.

Table 1

TYPICAL 3(s) RANDOM ANGULAR ERROR FOR VARIOUS INSTRUMENTS

Instrument Class: Least Division of Micrometer, Scale, or Vernier

	1"	6"	10"	20"	30"	1'
3s	7.0"	7.4"	7.5"	10.5"	13.0"	15.0"

Table 2

TYPICAL 3(s) OF TARGET CENTERING ERROR

3(s)	Method of Plumbing Target
0.0015 feet	Forced centering (leapfrog tripods)
0.005 feet	Independent tripod setups
0.020 feet	Waist-high plumb-bob (no wind)
0.026 feet	Top of 4-foot plumbed range pole
0.030 feet	Head-high plumb-bob (no wind)
0.040 feet	Top of 3-foot lath over point
0.053 feet	Top of 8-foot-high plumbed range pole

Figure 1. (cont.)--Program steps.

and 4- and 8-foot-high plumbed range poles. The values for plumb-bob and lath targets have no statistical backing and are presented as a guide until better values are determined.

PROGRAM LISTING & STORAGE REGISTERS

Figure 3 contains the actual program listing. The following are the storage registers used by the program:

```

00 Pointer (leg number)
01 3(s) instrument default
02 3(s) target default
03 EDM/MM/COR
04 EDM/PPM/COR
05 Closing distance ( $E_c$ )
06 Angular closure
07 Horizontal distance FS
08 Angular error of leg2 ( $A_s^2$ )
09 3(s) target FS
10 Sum error radii2 ( $E_u^2$ )
11 Sum horizontal distances
12 Sum angular error2 ( $E_p^2$ )
13 Horizontal distance BS
14 Pointer FS, BS distance
15 Error radius of leg2 ( $E_r^2$ )
16 Number of distance repetitions default
17 Single angle repetitions default
18 Number of distance repetitions of leg
19 Angle pairs of leg
20 Pointer FS/BS target type
21 3(s) target BS
22 Error linear of leg ( $E_d$ )
23 3(s) instruments of leg

```

SAMPLE ANALYSIS

A 1-minute transit and an EDM were used to perform the sample traverse in figure 4. Station 1 and 6 are section corners, station 3 is a temporary point for the lost quarter corner between them and the other stations are random traverse points. Station 10 is common to and closes on station 1. A lath approximately 3 feet long was used as a target for all fore- and backsights. Two distances and one direct and reverse pair of horizontal angles (two single angle repetitions) were measured at each station. Upon execution of the program, "SAMPLE" was keyed in for the label prompt. From table 1, 15 was keyed for the 1-foot transit default. From table 2, 0.04 was keyed for the 3-foot lath used as targets. The EDM millimeter and parts per million corrections each were 5.

d = Distance
 s = Standard deviation
 IE = Instrument pointing and reading error (angular)
 TE = Target centering error (linear)
 BTE = Angular error from backsight target miscentering
 FTE = Angular error from foresight target miscentering
 A_s = Angular error per station
 E_d = Position error from distance / station
 E_a = Position error from angle / station
 E_r = Greater of the position errors (E_d or E_a / station)
 E_p = Propagated angular error
 E_u = Estimated uncertainty of position of any point in relation to starting point

$IE = \text{Value from table 1} / \sqrt[4]{\text{Angle pairs}}$

$TE = \text{Value from table 2}$

$BTE = \text{ARCSIN} \left(\frac{\text{Backsight TE}}{\text{Backsight } d} \right)$

$FTE = \text{ARCSIN} \left(\frac{\text{Foresight TE}}{\text{Foresight } d} \right)$

$A_s = \sqrt{IE^2 + BTE^2 + FTE^2}$

$E_d = 3 * \sqrt{(\text{EDM constant})^2 = (d * \text{ppm})^2 + (\text{Foresight TE} / 3)^2}$

$E_a = \text{SIN}(A_s) * d$

$E_p = \sqrt{A_{s1}^2 + A_{s2}^2 + \dots A_{sn}^2}$

$E_u = \sqrt{E_{r1}^2 + E_{r2}^2 + \dots E_{rn}^2}$

Figure 2.--Formulas used in estimate of uncertainty.

01 LBL "EU"	68 LBL a	135 LBL 32	205 HMS
02 LBL A	69 SF 09	136 FS? 01	206 XEQ 23
03 FC? 55	70 ADV	137 GTO D	207 HR
04 CF 21	71 0.50000	138 "DEFAULT Y, N"	208 CLD
05 SF 00	72 STO 00	139 PROMPT	209 SF 21
06 CF 01	73 "CLOSING DIST"	140 GTO 32	210 SIN
07 FIX 4	74 9999		211 RCL 07
08 CF 09	75 PROMPT	141 LBL E	212 *
09 CF 08	76 STO 05	142 SF 00	213 "< ERROR - FT."
10 CLRG	77 "< CLSRE"	143 GTO 01	214 XEQ 23
11 FC? 55	78 PROMPT		215 RCL 22
12 GTO 01	79 STO 06	144 LBL D	216 "DIST. ERROR"
13 SF 12	80 ADV	145 CF 00	217 XEQ 23
14 ADV	81 "BS DIST."		218 X<=Y?
15 "LABEL"	82 PROMPT	146 LBL 01	219 X<>Y
16 AON	83 XEQ 22	147 "DIST. REPS."	220 X12
17 PROMPT	84 STO 07	148 RCL 16	221 STO 15
18 AVIEW	85 GTO 31	149 FS? 00	222 SF 09
19 AOFF		150 XEQ 16	223 ST+ 10
20 ADV	86 LBL B	151 STO 18	224 RCL 07
21 "ESTIMATE OF"	87 FC? 09	152 "3S TARGET BS"	225 ST+ 11
22 XEQ 24	88 GTO 01	153 XEQ 17	226 RCL 08
23 "UNCERTAINTY"	89 ADV	154 XEQ 19	227 ST+ 12
24 XEQ 24	90 CF 08	155 "3S TARGET FS"	228 ISG 00
25 CF 12	91 "BACK UP ERROR"	156 XEQ 18	229 CF 09
26 ADV	92 AVIEW	157 XEQ 19	230 CF 08
27 ADV	93 PSE	158 RCL 07	231 GTO 31
	94 GTO a	159 RCL 04	
28 LBL 01		160 *	232 LBL C
29 "DEFAULTS"	95 LBL 01	161 X12	233 SF 08
30 AVIEW	96 FS? 08	162 RCL 03	234 FC? 55
31 XEQ 15	97 GTO 01	163 X12	235 CF 21
32 STO 01	98 RCL 15	164 +	236 "-----"
33 "3S, TABLE 2"	99 ST- 10	165 RCL 09	237 SF 12
34 PROMPT	100 RCL 08	166 3	238 XEQ 24
35 XEQ 22	101 ST- 12	167 /	239 CF 12
36 STO 02	102 RCL 07	168 X12	240 ADV
37 ADV	103 ST-11	169 +	241 SF 21
38 "EDM/MM/COR"	104 RCL 13	170 SQRT	242 RCL 11
39 PROMPT	105 STO 07	171 3	243 "DISTANCE"
40 XEQ 22	106 1	172 *	244 XEQ 23
41 39.37	107 ST- 00	173 STO 22	245 ADV
42 ENTER↑	108 SF 08	174 RCL 01	246 "STATISTICAL"
43 12		175 XEQ 15	247 FC? 55
44 /	109 LBL 31	176 10000	248 "STAT"
45 1000	110 ADV	177 /	249 "CLOSURE"
46 /	111 ADV	178 HR	250 AVIEW
47 *		179 STO 23	251 FIX 0
48 STO 03	112 LBL 01	180 RCL 17	252 RCL 10
49 "EDM/PPM/COR"	113 SF 21	181 "< REP	253 SQRT
50 PROMPT	114 "STA"	182 FS? 00	254 /
51 XEQ 22	115 RCL 00	183 XEQ 16	255 "1: "
52 ADV	116 INT	184 2	256 ARCL X
53 1 E6	117 1	185 /	257 AVIEW
54 /	118 +	186 STO 19	258 FIX 4
55 STO 04	119 FIX 0	187 RCL 23	259 XEQ 21
56 "DIST. REPS."	120 SF 12	188 RCL 19	260 SF 21
57 RCL 16	121 XEQ 23	189 SQRT	261 RCL 12
58 XEQ 16	122 CF 12	190 SQRT	262 SQRT
59 STO 16	123 FIX 4	191 /	263 HMS
60 "< REPS."	124 XEQ 21	192 X12	264 "ER <"
61 RCL 17	125 "HOR DIST."	193 STO 08	265 XEQ 23
62 XEQ 16	126 PROMPT	194 XEQ 18	266 ADV
63 STO 17	127 SF 08	195 XEQ 20	267 9999
64 "-----"	128 RCL 07	196 XEQ 17	268 RCL 05
65 SF 12	129 STO 13	197 XEQ 20	269 X<Y?
66 XEQ 24	130 X<>Y	198 "*** ERROR"	270 GTO 01
67 CF 12	131 X=0?	199 "POTENTIAL"	271 GTO 02
	132 GTO C	200 "I-***"	
	133 XEQ 22	201 XEQ 24	
	134 STO 07	202 RCL 08	
		203 SQRT	
		204 "< ERROR - DEG"	

Figure 3.--Program used to estimate uncertainty.

272 LBL 01	333 LBL 18
273 FIX 0	334 7
274 "FIELD"	335 STO 14
275 FC? 55	336 9
276 "FLD"	337 STO 20
277 "—CLOSURE"	338 RTN
278 AVIEW	
279 "1: "	339 LBL 19
280 RCL 11	340 RCL 02
281 RCL 05	341 ENTER
282 /	342 FS? 00
283 ARCL X	343 PROMPT
284 AVIEW	344 STO IND 20
285 FIX 4	345 X=Y?
286 RCL 05	346 XEQ 22
287 SF 21	347 RTN
288 "ER LNR "	348 LBL 20
289 XEQ 23	349 RCL IND 20
290 "ER <"	350 RCL IND 14
291 RCL 06	351 /
292 XEQ 23	352 ASIN
293 ADV	353 X42
294 LBL 02	354 ST+ 08
295 FC? 55	355 RTN
296 CF 21	356 LBL 21
297 ADV	357 SF 21
298 "-----"	358 RCL 10
299 SF 12	359 SORT
300 XEQ 24	360 "EU"
301 CF 12	361 XEQ 23
302 CF 21	362 FC? 55
303 "NOW WHAT ? "	363 CF 21
304 AVIEW	364 RTN
305 FS? 55	
306 SF 21	365 LBL 22
307 STOP	366 "—= "
308 GTO A	367 FC? 55
	368 RTN
309 LBL 15	369 ACA
310 RCL 01	370 ACX
311 "3S, TABLE 1"	371 ADV
312 FS? 00	372 RTN
313 PROMPT	
314 X<0?	373 LBL 23
315 GTO 15	374 FS? 55
316 X=Y?	375 GTO 22
317 XEQ 22	376 SF 21
318 RTN	377 "—= "
	378 ARCL X
319 LBL 16	379 AVIEW
320 ENTER	380 RTN
321 FIX 0	
322 PROMPT	381 LBL 24
323 X=Y?	382 FC? 55
324 XEQ 22	383 RTN
325 FIX 4	384 ACA
326 RTN	385 ADV
	386 RTN
327 LBL 17	387 END
328 13	
329 STO 14	
330 21	
331 STO 20	
332 RTN	

Figure 3. (cont.)--Program used to estimate uncertainty.

DEFAULTS

3S, TABLE 1 = 15.0000
3S, TABLE 2 = 0.0400

EDM/MM/COR = 5.0000
EDM/PPM/COR = 5.0000

DIST. REPS. = 2.
< REPS. = 2.

BS DIST. = 551.0000

STA = 1.

EU = 0.0000
HOR DIST. = 610.0000
*** ERROR POTENTIAL ***
< ERROR - DEG = 0.0025
< ERROR - FT. = 0.0744
DIST. ERROR = 0.0641

STA = 2.

EU = 0.0744
HOR DIST. = 2,013.0000
*** ERROR POTENTIAL ***
< ERROR - DEG = 0.0021
< ERROR - FT. = 0.2011
DIST. ERROR = 0.0702

STA = 3.

EU = 0.2144
HOR DIST. = 986.0000
*** ERROR POTENTIAL ***
< ERROR - DEG = 0.0018
< ERROR - FT. = 0.0844
DIST. ERROR = 0.0651

STA = 4.

EU = 0.2305
HOR DIST. = 973.0000
*** ERROR POTENTIAL ***
< ERROR - DEG = 0.0019
< ERROR - FT. = 0.0904
DIST. ERROR = 0.0651

STA = 5.

EU = 0.2475
HOR DIST. = 842.0000
*** ERROR POTENTIAL ***
< ERROR - DEG = 0.0020
< ERROR - FT. = 0.0809
DIST. ERROR = 0.0647

STA = 6.

EU = 0.2604
HOR DIST. = 3,647.0000
*** ERROR POTENTIAL ***
< ERROR - DEG = 0.0018
< ERROR - FT. = 0.3193
DIST. ERROR = 0.0838

STA = 7.

EU = 0.4120
HOR DIST. = 2,010.0000
*** ERROR POTENTIAL ***
< ERROR - DEG = 0.0016
< ERROR - FT. = 0.1531
DIST. ERROR = 0.0702

STA = 8.

EU = 0.4396
HOR DIST. = 1,783.0000
*** ERROR POTENTIAL ***
< ERROR - DEG = 0.0016
< ERROR - FT. = 0.1403
DIST. ERROR = 0.0688

STA = 9.

EU = 0.4614
HOR DIST. = 551.0000
*** ERROR POTENTIAL ***
< ERROR - DEG = 0.0022
< ERROR - FT. = 0.0580
DIST. ERROR = 0.0640

STA = 10.

EU = 0.4658

DISTANCE = 13,415.0000

STATISTICAL CLOSURE
1 : 28,798.

EU = 0.4658
ER < = 0.0059

FIELD CLOSURE

1 : 13,152.
ER LNR = 1.0200
ER < = 0.0050

DISTANCE = 13,415.0000

STATISTICAL CLOSURE
1 : 28,798.

EU = 0.4658
ER < = 0.0059

FIELD CLOSURE

1 : 34,397.
ER LNR = 0.3900
ER < = 0.0000

Figure 4.--Sample estimate of uncertainty.

The closure initially input was the closure before angle adjustment (1.02 feet and 50 seconds). The backsight distance in this case was known, because it was the same as the last leg of the traverse, 551 feet. After all the distances were input, "C" was keyed to calculate the statistical closure.

The program then made a comparison of expected angular closure and actual angular closure computed from field data. The program indicated that the maximum random angular error expected to accumulate is 59 seconds. Actual angular closure was 50 seconds. This shows that the 50 seconds of error is in the realm of random accumulation and can be distributed by the rules of random error adjustments. By looking at the potential error at STA - 1 of 25 seconds and the 16 seconds at STA - 8, it becomes rather obvious the 50 seconds of error should not be equally divided between the stations. STA 1 should get 2.4 times the correction of STA 8:

$$25^2 / 16^2 = 2.44$$

STA 2 should get 1.7 times the correction of STA 8:

$$21^2 / 16^2 = 1.72, \text{ and so on.}$$

At this point, the angles were adjusted and a new closure computed, and rather than 1.02 feet there were 0.39 feet of "unaccountable error." The expected maximum closure was 0.47 feet. The field closure is in the realm of random accumulation and the distance error can be distributed by the rules of random error adjustments.

If we assume a positional tolerance of 2 feet between a quarter corner and each of its controlling section corners, we can calculate how accurately we need to measure between the section corners to ensure that the standard is met:

$$\sqrt{2^2 + 2^2} = 2.8$$

The difference between E_u of one section corner and the other must be less than 2.8 feet. In this sample, the difference between E_u of STA 1 and STA 6 is 0.26 feet. This shows that our methods of traverse can easily meet the standard. Our field closure was less than the expected closure therefore our measurement between section corners will meet the standard.

The temporary point for the 1/4 corner (STA 3) had an uncertainty of 0.21 feet from STA 1 and 0.15 from STA 6. This meant our methods to get from the temporary point to the true point must ensure no more than 1.99 feet of random error.

$$\sqrt{0.21^2 - 0^2} = 0.21$$

$$\sqrt{0.26^2 - .21^2} = 0.15$$

$$\sqrt{2^2 - 0.21^2} = 1.99$$

Had the field closure been 1.02 feet after proper angular adjustment, we would have assumed that our error was not random in nature, that a blunder had occurred, and that the blunder could be 1.02 feet in any leg. The tolerance for setting the quarter corner (2 feet) would not be exceeded by this one foot bust. However, if a 1/16 corner were to be set within a 1-foot tolerance, the 1.02 foot bust would become significant.

(EFN)

A Primer on Satellite Sensors

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EDITOR'S NOTE

The following article is the first of a series (we hope) of short articles designed to help you know and understand specialized terms from new fields. We hope the articles will keep you thinking--that they ultimately will result in the increased use of advanced technology. We want high technology to become low technology; we want it to become a common part of our lives in the management of the public lands.

We plan to publish these "primers" occasionally when they appear to meet a need of Field Notes' readers. Please let us know if there are topics that you would want to see covered. All readers are encouraged to submit similar articles.

INTRODUCTION

"Space: the final frontier."

Everyone who has watched Star Trek will recognize Captain Kirk's words as he introduces the program. Space is no longer a realm occupied by writers of fiction. We are there now, looking back and collecting data about the spaceship Earth.

Sensors operated from space will have an increasing importance in the literature of remote sensing. Reading about digital data from the sensors will take more of our time. Specialists will be called upon more and more to explain what the data mean and to find ways to use that data in resource management. This article is designed to help you understand a few of the basic terms that are used in this field.

TERMS

Apogee. In describing an orbit, the apogee is the point on an elliptical orbit that is the farthest

away from the body being orbited. It usually may be interpreted as the point farthest from the body's surface, such as the Earth's sea level.

Perogee. In describing an orbit, the perogee is the point on an elliptical orbit that is the closest to the center of gravity of the body being orbited. It usually may be read as the point of the orbit that is closest to the body's surface, such as the Earth's sea level.

Orbit. The circular or elliptical path described by a satellite as it revolves around a planet, moon, or other satellite.

Absolute Altitude. The altitude of a spacecraft above the actual surface (either land or water) of a planet or moon.

Launch Window. The exact date and time limits that must be met if a satellite is to be successfully inserted into a prescribed orbit. For example, if a satellite is to be placed into a sun-synchronous orbit so that it will pass over all latitudes at 10:00 a.m. (local sun time), there are very strict requirements about where and when the satellite must be launched.

Ground Track. The path of a satellite over land or water that falls directly below the passing satellite. It normally is shown as a line on a map that illustrates the satellite's path. Observers standing on that line could look vertically up and "see" the satellite.

ERTS (Earth Resources Technology Satellite). The name of the first Earth resource satellites launched by the United States. They carried electro-optic scanning sensors. They were later renamed Landsat.

Landsat. Renamed from ERTS, the Landsat satellites are sun-synchronous, electro-optic sensors that collect information about light reflected from the Earth's surface. Several different wavelengths (colors) of light are detected and their intensities are recorded. The data are reassembled into usable images or into computer-compatible tapes at a ground processing facility.

Seasat. Similar to Landsat, this series of satellites is designed to monitor the conditions and

movements of the Earth's oceans. They use radar to determine many characteristics of ocean waves, surface elevation, and currents.

Spot. The French launched the Spot satellite as their entry into the Earth resources monitoring business. It has better resolution than the U.S. Landsat and is capable of collecting overlapping images that provide, for the first time, stereo coverage of Earth scenes from space.

Synchronous Satellite. A satellite in Earth equatorial orbit at an altitude of 35,900 kilometers. At this altitude, the satellite makes one revolution of the Earth in 24 hours synchronous with the Earth's rotation. To an observer on Earth, the satellite appears to be stationary in the sky. Satellites relaying television transmissions are of this kind.

Sun Synchronous. An Earth polar orbit with an altitude such that the satellite passes over all places on Earth having the same latitude, twice a day at the same local sun time.

Hydrazine. A chemical (oxidized nitrogen) that is used as a fuel to supply energy for satellite altitude control.

Insertion. The act of placing a satellite into a prescribed orbit. This is done either by launching on an expendable launch vehicle (ELV) or by deploying from a manned craft such as the Space Shuttle.

Tracking Station. A ground facility that tracks a satellite's passing with radio antennas. Data collected by the satellite sensors are stored on board the satellite and "dumped" on command to data recorders on Earth. The tracking stations also "upload" commands and updated data that are essential to the proper functioning of the satellite and the sensors.

Nominal Orbit Altitude. A general description of the altitude of a satellite. Orbits are mathematically complex and cannot be described in simple terms. This description of altitude gives the reader a general knowledge of the satellite's place in space in relation to the Earth.

STS (Space Transportation System). The best known component is the Space Shuttle, but the system comprises many support activities.

GOES (Geostationary Operational Environmental Satellite). A satellite deployed to receive data transmissions from remote and unmanned Earth-based sensors and to relay the data to central collection and processing stations. Satellites of this type have been used to collect data from automatic stream flow monitoring stations and from snow pack sensors.

Polar Orbit. An Earth orbit in which the satellite passes over the north and south poles.

Equatorial Orbit. An Earth orbit in which the satellite follows the Earth's equator in its West to East flight.

ADDITIONAL INFORMATION

For more information, readers may want to refer to recent encyclopedias or to textbooks on the physics of orbital dynamics. The Manual of Remote Sensing, edited by Robert N. Colwell (2nd ed., Falls Church: American Society of Photogrammetry), contains some excellent reviews of many of these terms. Some of the definitions in this article are paraphrased from this manual.

EFN

Central Tire Inflation Program—Boise National Forest Field Evaluation

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INTRODUCTION

Currently, the Forest Service maintains more than 342,000 miles of roads to transport forest products from National Forests. Approximately 95 percent of these roads are unpaved. The cost of transporting forest products includes not only the actual cost of transportation, but also the cost of constructing and maintaining the roads. Efforts to save dollars mean a need to develop better road technology to reduce costs incurred in all phases of road construction and use. Much of the direction for doing this is set by the Road Technology Improvement Program (RTIP).

Under RTIP direction, the San Dimas Equipment Development Center (SDEDC) is investigating the effects of tire pressure on the cost of transporting forest products over Forest Service haul roads. An initial report on this investigation can be found in the Engineering Field Notes article, "Using Central Tire Inflation Systems to Decrease Vehicular Damage to Forest Roads" (L.B. Della-Moretta, Vol. 15, January-March 1983, pp. 17-19). To begin to quantify the relationship between logging truck tire pressure and road and haul costs, and to familiarize the logging industry with the low tire pressure concept, the Forest Service is conducting a two-part test program.

Part one consists of structured tests to quantify the interrelationship between tires, the road, and the vehicle and the associated benefits of low tire pressures. Part two consists of a series of field tests that should demonstrate to the logging industry the concept of low tire pressure and qualitatively evaluate the effectiveness of central tire inflation (CTI) systems under actual field conditions.

FIELD DEMONSTRATION TEST PLAN

The Moores Creek timber sale on the Boise National Forest near Cascade, Idaho, was to be the first field test to use low tire pressure on an actual timber haul. This operation was selected to demonstrate safely the concept and associated benefits of hauling logs with lowered tire pressures and to determine the effects on haul costs, driver comfort and fatigue, road maintenance requirements, and length of haul season.

The entire 11-mile haul route was over unpaved roads--5 miles of aggregate-surfaced county road and 6 miles of native-surfaced Forest Service road with tight curves and grades up to 12 percent. An administrative closure, effective the first day of the test program, was placed on the Forest Service segment of the haul route, restricting the test area to just the logging traffic.

To test the low tire pressures, the Forest Service, the Boise Cascade Corporation, and Hanson Logging of Horseshoe Bend, Idaho, agreed to change the operating plan for the Moores Creek timber sale for the 1986 fall operating season. From September to November 1986, four 18-wheel western logging trucks were operated with low tire pressures to haul approximately 1.7 million board feet of timber from the sale area. This is just one of many projects to be conducted throughout the United States to involve a wide variety of regional conditions; the comments and observations that result from this test plan depend upon the conditions peculiar to this sale area.

TEST PROCEDURE

Immediately before testing, all four trucks were equipped with radial tires. Unlike traditional bias ply tires, newer radial tires perform more effectively when they are run at pressures more appropriate for a particular operational load and speed. Since CTI systems were not yet fully developed and available for this test, tire pressure adjustments were made manually. Ordinarily, logging trucks operate with air in their tires set at from 90 to 110 pounds per square inch (psi). For the Moores Creek sale, the driving axle tires were set at 41 psi for the loaded condition. Trailer axle tires were set at 38 psi for the entire low-pressure test, since they were carried, or "piggy-backed," on the return trip.

As an experimental precaution, steering axle tires were set at 54 psi for the entire low tire pressure phase. When the trucks were unloaded at the Boise

Cascade mill, the truck drivers deflated the driving axle tires to 25 psi by using automatic deflation valves that had been plugged onto the tire valve stems. By using various pressures, tire footprint length and deflection were kept constant for different loads during the low pressure phase (figure 1). Tire deflection is the amount of

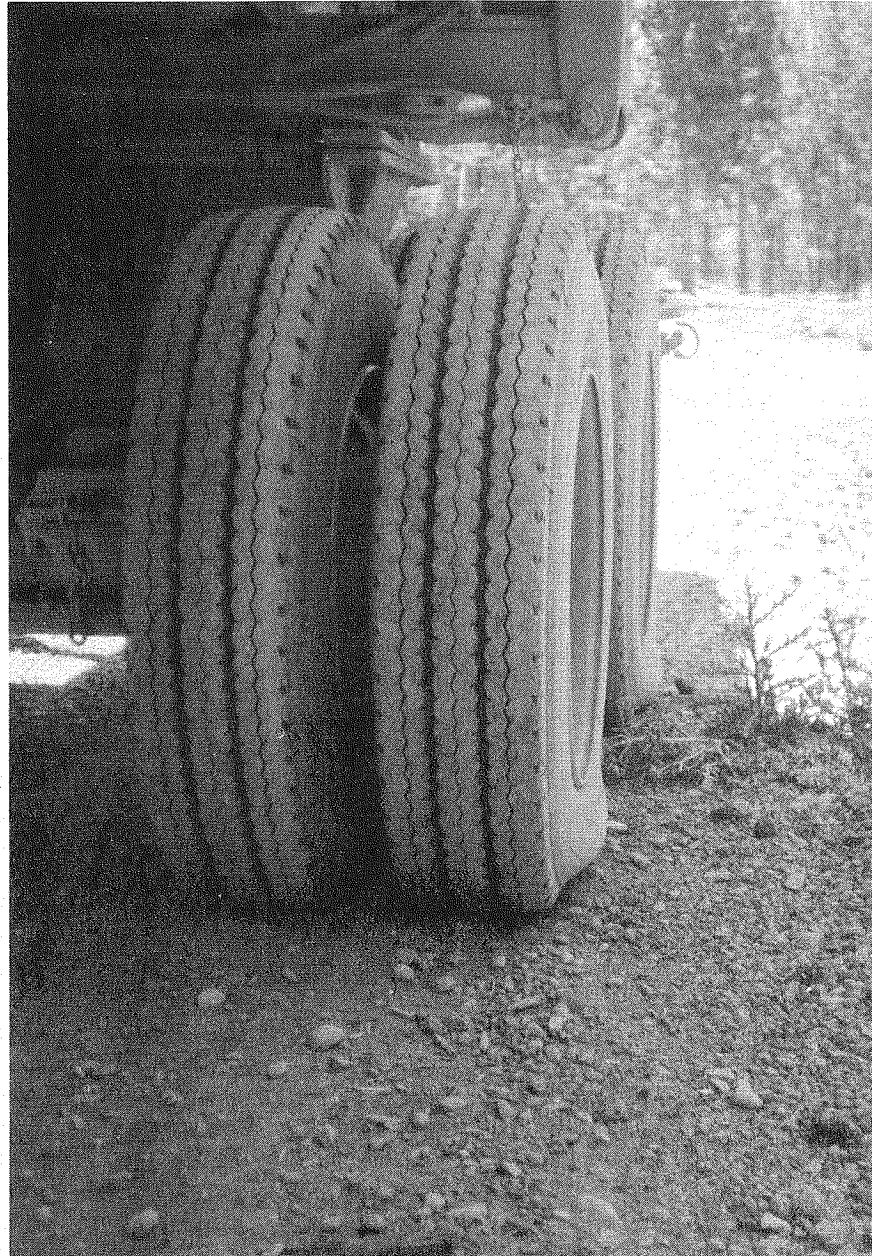


Figure 1.--Increased deflection of radial tires with lowered air pressure looks "bad," works great.

flatness of a tire; for example, tires inflated to 100 psi typically are deflected by 10 percent of their section height. Constant deflection and footprint length were important to ensure consistent results during low-pressure testing.

Limited field measurements were taken during the test program, because the test was to be a demonstration having mostly subjective evaluations. Truck drivers were responsible for keeping a daily record of fuel consumption, round trip times, and total loads hauled. Records were made of any tire or rim damage--including conditions causing the damage, the type of damage, tire mileage, tire pressure, and position of the tire on the vehicle. A radar gun was used to determine the speed of each vehicle through the test segments and other designated segments of the haul route.

Five test segments were selected along the haul route to record the effects of changing tire pressures under a wide variety of road conditions: curves, grades, surface soil types, and moisture changes. At the beginning and end of each phase of testing, nuclear moisture/density readings (to be verified with an oven-dry sample) and documentation photographs were taken at each test segment.

Measurements of road rutting and related strain were taken at a designated location by Dan Salm from the Forest Service Graduate Program, Oregon State University. Once truck drivers or test personnel observed washboard corrugation or road rutting, depth measurements were recorded and photographs taken to document the progression. A rain gauge was installed to record daily precipitation.

TEST RESULTS

Since an objective of the tests on the Boise National Forest Cascade Ranger District was to provide a qualitative evaluation of the low tire pressure concept, this discussion of test results is based primarily upon comments and observations made during the test program. Of the approximately 1.7 million board feet of timber hauled during the test program, 1.0 million board feet was transported on trucks with low tire pressures and the remaining 0.7 million board feet with high tire pressures. After the first 4 days of haul with low tire pressure, weather conditions changed, and the road surface became so wet that the haul was temporarily shut

down. Subsequent hauls were accomplished by alternating high and low tire pressures, as road and weather conditions changed.

Reduced Haul Costs

Condition surveys of the vehicles before and at the conclusion of the test program indicated that no additional maintenance or repair was required on the vehicles after hauling the 1.7 million board feet. This is important, because costs associated with truck maintenance and repair are a significant portion of the overall haul costs. The truck drivers agreed that, over an extended time period, overall truck maintenance repair would be decreased by the use of low tire pressures. They believed that over a period of time both the frequency and degree of truck repair would decrease.

One of the largest haul cost factors to be improved is tire replacement. Bruises, breaks, and cuts currently are the predominant cause of premature tire failure on logging trucks. With a longer tire footprint, the low-pressure tires actually rolled over large, sharp rocks, that protruded above the road surface on low-speed, weak roads without the tire damage commonly seen. The increased bulge in the tire sidewalls eliminates the tendency for rocks to get caught between the duals and cause a blowout. In fact, during this test program, the only blowout resulting from a rock caught between the duals occurred during a high-pressure phase.

Upon completion of the test program, the trademark design molded within the tire tread area by the tire manufacturer was still evident, indicating limited tire wear. Following an examination of some of the tires by Bandag, Inc., of Muscatine, Iowa, for possible tire damage and retreading, additional miles will be run using the tires from this test program.

Increased Driver Comfort

By lowering tire pressures, tire deflection increased and the tire footprint lengthened. Hence, the tire is in contact with the road surface for a longer period of time. The drivers noticed less bouncing and rattling of their trucks and less discomfort on their backs.

Because of the short duration of low-pressure operation, the drivers did not get used to the feel of handling and stability associated with low pressure. Power steering would have helped with the handling,

Reduced Road Maintenance

since the longer footprint requires more power to turn the steering tires. The drivers felt some handling difference in curves. However, subsequent tests and inspection found this to be because of the bunk pads on the trailer rather than the tire pressure. Drivers agreed that overall stability was improved, and felt that a truck rollover was avoided because of the lowered tire pressure.

To both the logging truck drivers and the Forest Service, changing tire pressures improved the road surface conditions and decreased overall road maintenance requirements. According to Al Noyes of the Cascade Ranger District, road deterioration did not occur for either the low- or the high-pressure phases. This was dramatically different than the previous haul year, when the road had required continual maintenance. For this test, the first low-pressure test phase set the road surface up so hard and smooth that only in areas of excessive subsurface water did the road surface break down under high pressure.

The repairing effect of low pressure became apparent early on in the test program. During the first low-pressure phase, when the roads became saturated and so slick that the haul operation was temporarily shut down, logging traffic other than the logging trucks had rutted and damaged the road surface with high pressure tires. After the road surface had dried out enough to resume haul, the first high tire pressure phase was planned to begin. However, based upon the suggestion of the logging contractor and truck drivers, 2 days of haul were run using low tire pressure in lieu of grading the road surface. The low tire pressures smoothed the road surface (figure 2) and grader maintenance was not required.

For the remainder of the test program, the road surface remained dry. The opportunity did not arise to haul on wet roads using high tire pressures. However, photographs documenting road conditions of this same haul road when it had been used a year earlier using normal tire pressures showed ruts as deep as 16 inches. Road maintenance had been continual. This same haul road never needed maintenance throughout the course of this test program. According to the Cascade Ranger District staff, it was almost too much to believe that 1.7 million board feet of timber was hauled with no maintenance to the road.



Figure 2.--Radial tires with lowered air pressure produce less stress on the road surface.

Extended Haul Season

Because of its road-healing characteristics, the use of low tire pressures could extend the actual haul season, particularly for wet or snow-covered road conditions. On steep grades, truck traction was improved by the use of low tire pressure. In the case of adverse haul over a wet road surface, the use of low tire pressure prolonged the haul and delayed a temporary shutdown.

The truck drivers recognized the possible advantage of using low tire pressure under snowy conditions. During the first heavy snowfall, when the road surface became slick and icy but was still warm enough to melt the snow, tires on all four trucks were inflated to normal pressures so that chains could be used. However, the drivers asked to have their tires deflated back down to lower pressures--

claiming that the road surface was not yet slick enough for chains, but recognizing that high pressure tires would not provide enough traction. Hauling resumed with all drivers using lower tire pressures.

CONCLUSIONS

The testing on the Moores Creek timber sale demonstrated that CTI technology can be beneficial in timber operations. Tests are now needed to quantify net cost benefits and identify any operational problems that must be overcome. Based upon the observations and comments made by both the Moores Creek logging crew and the Forest Service, the conclusion for this particular timber sale was that the use of low tire pressures could reduce overall haul costs, improve driver comfort, reduce road maintenance requirements, and extend the overall haul season.

This test was only one of a series of tests designed to determine the feasibility of using CTI systems to allow high tire pressures on high-speed, very strong roads and low pressures on low-speed, weaker unpaved roads. Development of these systems is underway. This and other tests are required to determine the feasibility of equipping logging trucks with CTI systems. The results of these tests indicate that the potential for future cost savings is tremendous. This may be the beginning of a whole new era of forest product transportation.

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