United States
Department of
Agriculture

Forest
Service

**Engineering
Staff**

Washington, D.C.

Seltzer

Volume 13
Number 4
April 1981

Engineering Field Notes

Engineering Technical Information System

ENGINEERING IN
A FORESTRY ENVIRONMENT

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PROFESSIONAL DEVELOPMENT • DATA RETRIEVAL • MANAGEMENT • FIELD NOTES • TECHNICAL REPORTS

INVITATION TO READERS OF
FIELD NOTES

Every reader is a potential author of an article for *Field Notes*. If you have a news item or short article you would like to share with Service engineers, we invite you to send it for publication in *Field Notes*.

Material submitted to the Washington Office for publication should be reviewed by the respective Regional Office to see that the information is current, timely, technically accurate, informative, and of interest to Forest Service Engineers (FSM 7113). The length of material submitted may vary from several short sentences to several typewritten pages; however, short articles or news items are preferred. All material submitted to the Washington Office should be typed double-spaced, and, ideally, all illustrations should be original drawings, glossy prints, or negatives.

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R-3	Juan Gomez	R-6	Kjell Bakke	WO	Al Colley
		R-8	Tom Vanderpool		

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Attn: Gordon L. Rome, Editor
P.O. Box 2417
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FIELD NOTES ARTICLES AWARDS - 1980

The rating for the Field Notes articles is complete, and the response from readers was most encouraging.

The articles were assigned a point value that reflects the rating by the readers: first - 3 points; second - 2 points; third - 1 point. The total number of points earned by each article was calculated to determine the ranking given below.

RANK	TITLE	AUTHOR(S)
1	Solar Bath & Toilet Facilities	Thomas Smith & William A. Speer (R-8)
2	Practical Solar Applications	James M. Kocer (R-3)
3	Describing Wilderness Boundaries -- Some Comments on Methods in General Use; One Land Surveyor's Viewpoint	C. C. Doak (R-3)

Congratulations to the winners! Checks will be forwarded as soon as the papers are processed.

The thanks of all Field Notes' readers are extended to the authors who took the time to write articles, in spite of heavy workloads and slim staffing. We appreciate the cooperation of the readers who submitted rating sheets, thereby demonstrating that the authors' efforts are of value to the field.

We are already one-third of the way through the year; submit YOUR article for the Field Notes Articles Awards for 1981. Tell other engineers how you accomplished a difficult job, or found a better way of handling a problem, or why a particular experience was interesting and valuable to YOU.

Send your article to

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SOME OBSERVATIONS on RECENT FIELD NOTES VOTING

(or "Stuffing the Ballot Box",
or "Shades of Old Tammany Hall",
or "The Carpet-Baggers' Return")

A WO protagonist of proper presentation of written communications was designated to perform a perfunctory perusal of the ballots received from parochial evaluators of the articles submitted for Field Notes in 1980. A peculiar possibility was posed by the preliminary observations, *to wit:*

A pervasive and perhaps pernicious situation was identified in which singular similarities in ciphers and concentrated selection (superimposed on the secondary reproduction medium utilized for the communication) seemed to signal a repetitious reporting of preference by a certain single reader (no connotations of marital status intended).

Presuming a potential for misinterpretation of the implications derived from the graphic record, a secondary review was made by peers of the correspondent concerned and by management levels, thereby precluding deductions that might be interpreted as derogatory or denoting a penury of either personal pride or professional position on the part of the correspondent. However, the conclusions of the secondary review supported the previous iteration of a strong olfactory excitation (non-Danish) that emanated from relationships in the correspondent's caligraphy that were specifically identified in the construction of the ordinal indicators of selection.

We wish to avoid assuming a pedantic position, or pontificating on the problem *ad infinitum,* or developing petulant respondents that resent the detailed inspection of the submittals. But, we also hope to preclude future obfuscation of the actual reflection of the readers' response factors.

.... *Ergo,* the ballots for selecting the most beneficial articles in the Field Notes in 1981 will be signed and dated by the readers submitting them.

---The Editor

FOUNDATION INVESTIGATION NORTH FORK TRINITY RIVER

Alex Tary
Geologist
Shasta-Trinity NF

Region 5

The foundation investigation of the North Fork of the Trinity River Weir entailed drilling to ascertain the thickness of the alluvium in the channel and the depth of the bedrock upon which the proposed structure could be erected. It should be noted that bedrock outcrops are present on both banks of the stream.

One major impediment existed: Excessive turbidity could be introduced in an active fishery by the task of getting the drill rig into the stream and moving it from drill hole to drill hole. After consultation with the California Department of Fish and Game and the California Water Quality Control Board, it was decided that entry into the stream with investigative equipment was justified.

Several solutions were considered to minimize turbidity, including the construction of a gravel berm to serve as a drilling platform. The cleanest and most practical solution appeared to be the use of a Caterpillar 966C front-end loader with logloading forks that was available for rental from a logging firm in the vicinity. The 966C loader, when adapted, afforded an ideal working platform for the drill rig furnished by the Umpqua National Forest R-6.

In order to adapt the loader to the task, a platform was built on the bottom forks from 2- by 12- and 2- by 4-foot lumber to provide the working area for the drill and the driller. Two heavy-duty garbage cans or two 55-gallon drums, depending on stream depth, were tied to the bottom of the logloading forks for stability. Additionally, this modification served to slow or prevent the bleed-down of the loader hydraulic system and the eventual sinking of the drilling platform. Figure 1 is a photograph of the 966C loader with the small drilling rig mounted on the forks.

An anonymous comment was expressed about the setup: "It sure looks like Mickey Mouse." Reply: "It worked -- and nicely at that."

Figure 1. 966C Loader with Drilling Rig

PHOTOGRAMMETRIC MEASUREMENTS FOR LAND SURVEYS NICOLET NATIONAL FOREST, WISCONSIN OTTAWA NATIONAL FOREST, MICHIGAN

Victor H. Hedman *Region 9*
Land Surveyor

INTRODUCTION

In FY 1958, the line program was initiated for locating, marking, and maintaining the boundaries of lands administered and managed by the Forest Service. Prior to that time, little had been done to maintain and perpetuate the corners and lines as established by the public land survey system; since then, the emphasis has been on the recovery, restoration, and establishment of corner positions that control the locations of National Forest boundaries. With the emphasis changing to boundary line locations and marking, the use of photogrammetric measurements for locating the boundary line between controlling corner positions is one of the techniques that is being considered and tested.

PHOTOGRAMMETRIC MEASUREMENTS

In 1958, the Forest Service Eastern Region used photogrammetric measurements as a pilot test project in the retracement and corner restoration survey of a township in Missouri. The project to determine if photogrammetric measurements could be applied to land surveys within acceptable limits of accuracy was undertaken in cooperation with the Washington Office and Phelps County, Missouri. The work included the establishment of section subdivisional corners and the retracement and recovery of existing corners. The results were marginal, compared to techniques and equipment now available for such projects.

Several years elapsed before photogrammetric measurements were started and completed on the Chequamegon and Ottawa National Forests for smaller two-section projects. In recent years, larger 8- and 16-section projects were started and completed on the Superior National Forest; none of these was done with the purpose of locating and marking the boundary line, and only corners were recovered, restored, established, and monumented. Using aerotriangulation coordinates for these corner positions, the proven measurement accuracies on these projects ranged from less than 1 foot in horizontal position to a marginal tolerance of 3 feet in position; the majority of the tests for accuracy of corner placement were within 1.5 feet of position when checked by closed ground traverse.

In a discussion of photogrammetric measurements for land surveys, there will be a question as to the attainable degree of accuracy and the tolerance error allowable. Is a positional accuracy of 1.5 feet (or a relative accuracy of 1 part in 3,000) supportable and defensible for the rural land surveys of National Forest boundaries? With the advent of electronic distance measurements, accuracies greater than those made with photogrammetric measurements are easily attainable, and this factor is reflected in standards of accuracy required in many of the States; however, it must be recognized that these requirements are "urban-oriented". The need for urban accuracies is not evident for National Forest lands, nor is there any known court case that has challenged photogrammetric measurements when proven photogrammetric techniques have been applied.

Techniques and equipment have improved since 1958, and further improvement can be expected; however, increased costs of narrowing the limits of tolerance may not be economically justified if present limits serve our needs. The accuracy of photogrammetric measurements will improve, but it is not evident that such measurements will match electronic measurements. Photogrammetry is one of the tools of measurement that has a significant place in land surveying and related fields, and the results of tests and limitations of photogrammetric projects on the Nicolet and Ottawa Forests are pertinent.

PHOTOGRAMMETRIC TEST PROJECTS

Error in photogrammetric measurement may result from several sources: ground control accuracies; quality and scale of aerial photographs; type of equipment used; and the level of skill and knowledge of project personnel.

The aerial photograph is controlled by ground targets of known coordinate positions, and it is further rectified for the tip and tilt and drift of the plane as each frame is exposed in flight. Bridging techniques by stereoplotter are used to tie photographs together. The small discrepancies in matching overlapping photographs to known points common to adjoining photographs are known as "residuals", inherent errors that require tolerance acceptance if photogrammetric measurements are to be used. The residuals cannot be reduced to zero by presently known techniques and equipment.

Nicolet National Forest

In Forest County, Wisconsin, a section was subdivided by photogrammetric measurements using controlled ground targets (figure 1). Targets were placed near the boundary lines that were to be located and marked, and the photogrammetric measurements from target to boundary line were compared with the field control location of the same lines (figure 2). The variance in photo measurements (subject to the inherent residuals of photo bridging) show that half the measurements are within 1 foot, and the maximum variance is 2.1 feet.

The photography of this section was done by flying a single north-south strip at a photo scale of 1 inch to 800 feet. The residuals and positional differences derived by the reading of eleven common points on overlapping photographs are shown in figure 3. Note that seven of the eleven positional differences were between 0.6 to 0.9 foot, which does not allow much tolerance for errors in field measurements if the positional accuracy requirement is 1 foot.

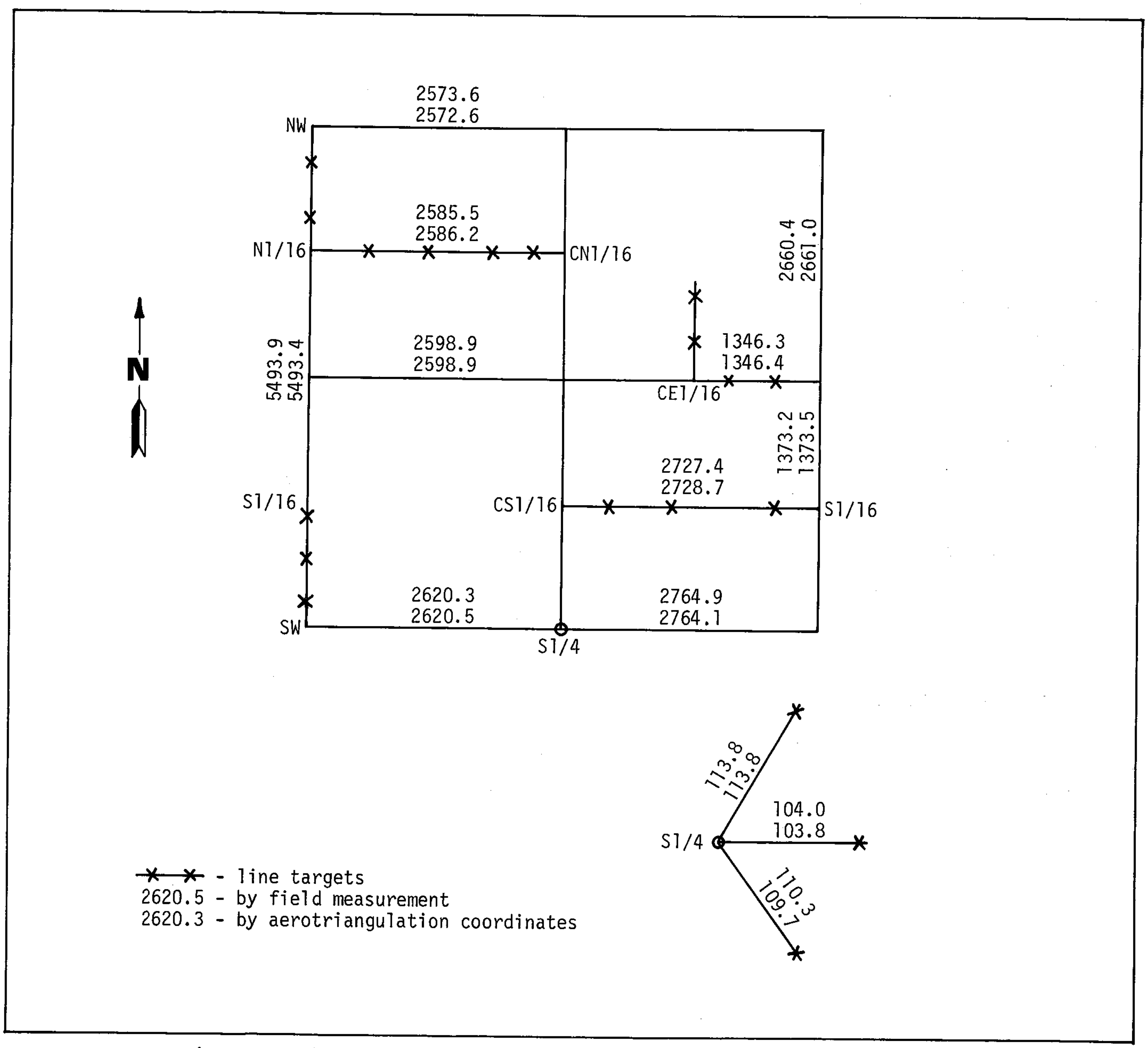


Figure 1.--Photogrammetric Measurements of Section 20 T34N R14E 4th P.M. Forest County, Wisconsin.

Line	Field Control	Photo Control	Variance in Feet
N 1/16th-NW	17.0 feet 16.2 3.6	16.3 feet 15.0 1.7	0.7 1.2 1.9
N 1/16th-CN 1/16th	39.7 89.8 75.1	40.8 91.0 73.0	1.1 1.2 2.1
CE 1/16th-North	20.3 28.8	21.1 30.0	0.8 1.2
CS 1/16th-S 1/16th	27.3 7.1 35.3 38.3	27.3 7.2 35.9 38.6	0.0 0.1 0.6 0.3
SW-S 1/16th	7.0	6.4	0.6

Figure 2.--Comparison of photogrammetric measurements with field control locations.

Residuals		Positional Difference
East	West	Feet
0.50	0.63	0.80
-0.73	0.34	0.81
0.71	0.03	0.71
1.03	0.41	1.11
-0.46	0.91	1.02
-0.85	0.20	0.87
-0.21	0.89	0.91
-0.44	-1.97	2.02
0.41	0.63	0.76
0.56	-0.28	0.63
0.47	-1.04	1.14

Figure 3.--Residuals and positional differences.

Ottawa National Forest

Testing can push limits and principles. We needed to determine if larger scale photography would provide greater accuracy. Using 1 inch to 500 feet photography, we attained results comparable to those attained by using 1 inch to 800 feet on the Nicolet project.

A second test was made to determine whether field control could be held to the absolute minimum; that is: could we obtain accurate results from offset target to the boundary line by knowing only: the distance between two controlling targeted corner positions on the Y axis, or, must we have known distances between targeted corner positions on both the X and Y axes of the stereomodel?

In a distance of 1 mile between two targeted corner positions on the Y axis, the error from six offset targets to the straight line between corners ranged up to 5 feet. As soon as we controlled the X axis, the variance dropped to 1.8 feet as the maximum difference. Obviously, there are no short cuts in principles and procedures to obtain reliable results.

CONCLUSIONS

Photogrammetric land survey projects have met FS Regional standards for accuracy: 1 part in 3,000 (1.5 foot positional accuracy). These accuracies will not meet some States' accuracy requirements; however, the latter are "urban-oriented" --involving the conveyance of lands in urban areas. We are not aware of any court cases that challenge photogrammetric measurements for land survey.

The Ottawa test proved we could not take any short cuts in establishing ground control for photogrammetric measurements from target to boundary line.

The Nicolet test project and other cited projects prove that we can meet 1.5 foot positional accuracies for restoring or establishing corner positions when using properly-spaced ground control and proper photogrammetric techniques and equipment. However, there are limits on the use of offset targets to locate a boundary line to the FSM required accuracy of 1 foot. The several completed projects indicate that a 2-foot tolerance would allow use of photogrammetric measurements, and the FSM requirements should be relaxed if photogrammetric measurements are to be used in locating the boundary line.

ESTIMATING PROJECT TRAVEL COST AND MILEAGE

John P. Haynes *Region 3*
Robert Harding
Civil Engineers

INTRODUCTION

"With the high cost of fuel and mileage targets it was a mistake to have torn down those remote work centers." This statement was overheard recently and may or may not have been valid. The work centers in question were in poor repair and were deemed not worth the required expenditures under the pollution abatement program. The proper question is: "Considering energy conservation and personnel ceilings, where are work centers justified?" Something more than intuition is needed to answer this question.

ANALYSIS

To help determine work center needs, the following expressions were derived relating project work, travel hours, work schedules, labor costs, per diem rate, and vehicle costs. The total costs are the sum of personnel costs for travel time, the vehicle costs, and the per diem costs. These formulas can be used to compare personnel travel time, miles, and costs for various work center alternatives or various work hour schedules.

P = total travel time in person-hours working out of the Ranger Station or other headquarters.

$$= \frac{2Jt_2}{d-2t_2}$$

P_{wc} = total travel time in person-hours working out of the work center.

$$= \frac{2J(t_1 + t_3W/d)}{W-2t_1-\frac{2Wt_3}{d}}$$

$$\Delta P = P - P_{wc}$$

M = Total Travel w/o W.C. in

$$\text{miles} = \frac{2Jl_2}{C(d-2t_2)}$$

M_{wc} = Total Travel w/W.C. in

$$\text{miles} = \frac{2J(l_1 + l_3W/_d)\,^{l}/t}{C(W-2t_1-\frac{2Wt_3}{d})}$$

$$\Delta M = M - M_{wc}$$

T = total travel costs working out of the Ranger Station or other headquarters.

$$= \frac{2J}{d-2t_2}\left(rt_2 + \frac{ml_2}{C}\right)$$

T_{wc} = total travel costs working out of a work center.

$$= \frac{J}{W-2t_1-\frac{2Wt_3}{d}}\left[2r\left(t_1 + t_3\frac{W}{d}\right) + \frac{2m}{C}\left(l_1 + l_3\frac{W}{d}\right) + \frac{WS}{d}\right]$$

$$\Delta T = T - T_{wc}$$

Where:

J = Project work (person-hours)

r = Average labor costs (\$/hour)

W = Length of workweek or stay in field (hours)

d = Length of work day (hours)

t_1 = Travel time HQ to WC (hours)

t_2 = Travel time HQ to project (hours)

t_3 = Travel time WC to project (hours)

l_1 = Distance HQ to WC (miles)

l_2 = Distance HQ to project (miles)

l_3 = Distance WC to project (miles)

C = Crew Size in one vehicle (persons)

m = Vehicle mileage cost (\$/mile)

S = Subsistence (\$/day)

Project Work (J) is the number of person-hours of work needed or planned on site. Travel time is not included.

Average labor costs (r) is the total appropriation charge for salaries for the crew per hour divided by the number of people on the crew. This must be adjusted for work schedules that require overtime payments.

The length of workweek or stay in field (W) describes how long the crew would work while at a work center before returning to the headquarters. If the crew worked a regular 40-hour week while at the work center before returning to the headquarters, W would equal 40. If they worked ten 8-hour days with 4 days off, W would equal 80.

The length of work day (d) would be 8 for a normal 8-hour day. Where work schedules call for two different work days such as eight 9-hour days and one 8-hour day, "d" would be the average, or 8.89 hours.

The crew size (C) refers to the average number of people riding in a vehicle. Where the crew rides in one vehicle, C would equal the number of people on the crew. Where more than one vehicle is used, C would equal the number of people on the crew divided by the number of vehicles.

The vehicle mileage cost (m) is the total cost including F.O.R., or other monthly costs plus the mileage charge. The monthly charge must be prorated to the estimated monthly miles driven. Where more than one vehicle is used, "m" will equal the average vehicle cost per mile.

When justifying the construction of, or the retention of a work center, compare the annual cost of the work center with the total travel cost savings when using the work center. Do not add in the results for projects which will not save money using the work center. If the work center is used for these projects, it will be to save miles. The additional cost of using the work center should not weigh against the justification of the work center.

Program Instructions, HP-97

These calculations can be easily done on desk top calculators such as the Hewlett-Packard HP-97. The following program was designed for the HP-97 and will calculate P, Pwc, ΔP, M, Mwc, ΔM, T, Twc, and ΔT. Magnetic cards containing the program are available from the authors, Region 3, Engineering Staff Unit.

The accompanying Work Center Travel Cost and Mileage Summary Sheet is used to summarize the estimated costs when more than one project is involved. Load the program into the calculator. Then enter the values for variables P through S into storage registers 0 through C. Press the button A to activate the program. The estimated travel time, miles, and costs will be printed.

Before accepting the calculations for an individual project, explore other possible project variables such as work schedules and crew sizes. Simply enter the changed variables into the appropriate storage registers and press button [A]. Enter on the work sheet the results for the project plan most likely to be used. Repeat the procedure for each project, summarizing the results on the work sheet.

To assist the estimator, an illustrative example is shown along with the step-by-step procedure of using the program.

Steps

1. Load program into calculator according to H-P instructions.

2. Key project variables into storage registers, one project at a time.

Variable	Sto Reg	Project 1	Project 2	Project 3	
J	0	800	1000	600	(p-hrs.)
r	1	7	7	7	($/hr.)
W	2	40	80	40	(hrs.)
d	3	8	10	10	(hrs.)
t_1	4	.75	.75	.75	(hrs.)
t_2	5	1.00	1.00	1.50	(hrs.)
t_3	6	.5	.25	.50	(hrs.)
l_1	7	15	15	15	(miles)
l_2	8	20	20	30	(miles)
l_3	9	10	5	10	(miles)
C	A	3	3	3	(people/vehicles)
m	B	.50	.50	.50	($/mile)
S	C	16	16	16	($/mile)

Example Work Center Values

Headquarters: HAPPY CREEK RD

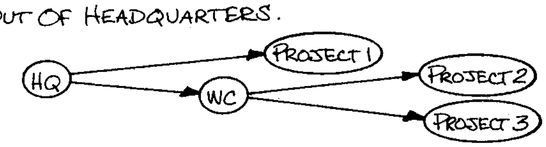
Done by: R. HARDING

Work Center Location: BUFFALO RUN WC

Date: 11 SEPT 80

Projects	Travel Time			Travel Miles			Travel Costs		
	P (person/hrs)	P_{WC} (person/hrs)	ΔP (person/hrs)	M (miles)	M_{WC} (miles)	ΔM (miles)	T (dollars)	T_{WC} (dollars)	ΔT (dollars)
1. ~~PROJECT 1~~	~~267~~	~~155~~	~~111~~	~~1,778~~	~~1,035~~	~~743~~	~~2,756~~	~~3,514~~	~~-759~~*
2. PROJECT 2	250	74	176	1,667	492	1,174	2,583	2,481	102
3. PROJECT 3	257	96	161	1,714	638	1,077	2,657	2,101	556
4.									
5.									
6.									
7.									
8.									
TOTALS of Cost Effective Projects Worked Out of Work Center.	507	170	337	3,381	1,130	2,251	5,240	4,582	658

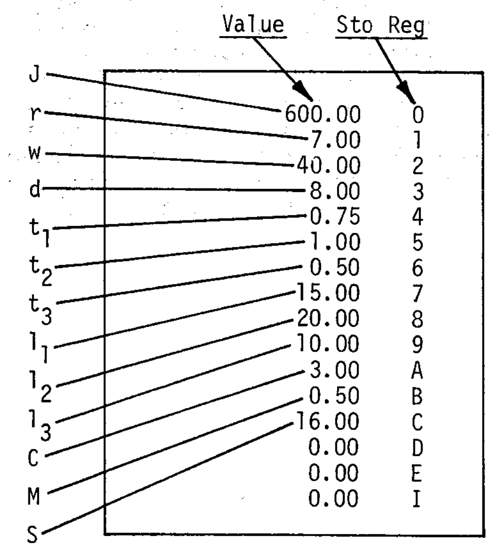
COMMENTS: * WORKING PROJECT 1 OUT OF THE WORK CENTER IS NOT COST EFFECTIVE THUS IT WAS ELIMINATED FROM CONSIDERING THE TOTAL TIME, MILEAGE, AND COST SAVINGS OF WORK CENTER AND WILL BE WORKED OUT OF HEADQUARTERS.



WORK CENTER TRAVEL COST & MILEAGE SUMMARY SHEET

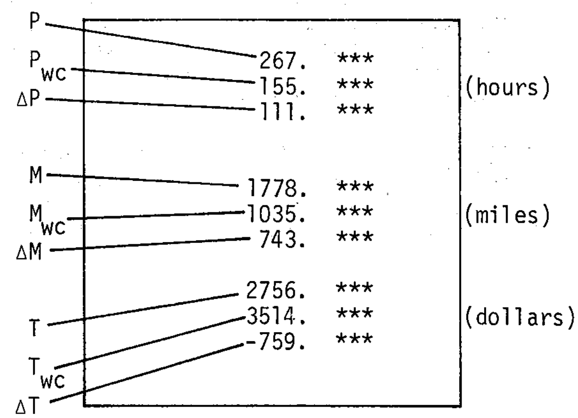
3. (Optional) Press [f] [PRINT REG] to check contents and accuracy of variables keyed into the storage registers.

Example Project #1 - Storage Register Printout



4. Press button [A], calculator will print out costs.

Actual Printout of Example Project #1



5. Repeat steps 2-4 for each project.

PROGRAM LISTING

Program Step	Function	Key Code
001	*LBLA	21 11
002	DSP0	-63 00
003	RCL0	36 00
004	RCL5	36 05
005	x	-35
006	RCL3	36 03
007	2	02
008	÷	-24
009	RCL5	36 05
010	-	-45
011	÷	-24
012	PRTX	-14
013	STOD	35 14
014	RCL2	36 02
015	RCL3	36 03
016	÷	-24
017	RCL6	36 06
018	x	-35
019	RCL4	36 04
020	+	-55
021	RCL0	36 00
022	x	-35
023	RCL2	36 02
024	2	02
025	÷	-24
026	RCL4	36 04
027	-	-45
028	RCL2	36 02
029	RCL6	36 06
030	x	-35
031	RCL3	36 03
032	÷	-24
033	-	-45
034	STOE	35 15
035	÷	-24
036	PRTX	-14
037	CHS	-22
038	RCLD	36 14
039	+	-55
040	PRTX	-14
041	SPC	16-11
042	RCLD	36 14
043	RCL5	36 05
044	÷	-24
045	STOD	35 14
046	RCL8	36 08
047	x	-35
048	RCLA	36 11
049	÷	-24
050	PRTX	-14
051	STOI	35 46
052	RCL2	36 02
053	RCL3	36 03
054	÷	-24
055	RCL9	36 09
056	x	-35
057	RCL7	36 07
058	+	-55
059	RCL0	36 00
060	x	-35
061	RCLE	36 15
062	÷	-24
063	RCLA	36 11
064	÷	-24
065	PRTX	-14
066	CHS	-22
067	RCLI	36 46
068	÷	-55
069	PRTX	-14
070	SPC	16-11
071	RCL8	36 08
072	RCLB	36 12
073	x	-35
074	RCLA	36 11
075	÷	-24
076	RCL1	36 01
077	RCL5	36 05
078	x	-35
079	+	-55
080	RCLD	36 14
081	x	-35
082	PRTX	-14
083	STOI	35 46
084	RCL2	36 02
085	RCLC	36 13
086	x	-35
087	RCL3	36 03
088	2	02
089	x	-35
090	÷	-24
091	RCL2	36 02
092	RCL9	36 09
093	x	-35
094	RCL3	36 03
095	÷	-24
096	RCL7	36 07
097	+	-55
098	RCLB	36 12
099	x	-35
100	RCLA	36 11
101	÷	-24
102	+	-55
103	RCL2	36 02
104	RCL3	36 03
105	÷	-24
106	RCL6	36 06
107	x	-35
108	RCL4	36 04
109	+	-55
110	RCL1	36 01
111	x	-35
112	+	-55
113	RCL0	36 00
114	x	-35
115	RCLE	36 15
116	÷	-24
117	PRTX	-14
118	CHS	-22
119	RCLI	36 46
120	+	-55
121	PRTX	-14
122	SPC	16-11
123	SPC	16-11
124	SPC	16-11
125	SPC	16-11
126	0	00
127	STOD	35 14
128	STOE	35 15
129	STOI	35 46
130	DSF2	-63 02
131	R	-31
132	RTN	24
133	R/S	51

CONCLUSIONS

Since developing these formulas, it became evident that a major use of the program will be for project planning. Whether or not a work center exists, travel time, miles, and costs can be estimated for alternatives such as different work schedules and crew sizes, or for using the work center or not using the work center.

Personnel ceilings and mileage constraints are becoming more important considerations and may justify using an existing work center or building a new one even where economics are not favorable. This program allows quick analysis so that the trade-offs can be considered.

This program was designed to compare the cost of working out of a work center with the cost of working out of a headquarters such as the Ranger Station. However, where crews are stationed at the work centers, costs can be compared for using different work centers by considering one work center as the headquarters and the other as the work center. Travel time from HQ to WC (t_1), and distance from HQ to WC (l_1) would then be entered as 0.

AN EMPIRICAL EVALUATION OF THE PRORATION OPTION OF MINCOST NETWORK PROGRAM

Peter Wong
Management Sciences Staff
U.S. Forest Service
Berkeley, Calif.

INTRODUCTION

The MINCOST Program has been used frequently in recent years by transportation analysts for network analyses in place of more sophisticated computer models such as the Timber Transport Model, Transshipment Model, and the Integrated Resource Planning Model. MINCOST appeals to users mainly because of simplicity in data input and insignificant computer run costs. When the problem is to obtain the best network, and where best is usually defined in terms of minimum total cost, the proration option is most often chosen.

The purpose of this paper is twofold. First, the heuristic algorithm used by the proration option is documented, since few users, if any, are familiar with the algorithm. Second, the characteristics of the algorithm are studied through a series of small hypothetical examples.

PRORATION ALGORITHM

The heuristic algorithm of the proration option is described below.

Step 1. Iteration = 1

For each timber sale, generate a minimum cost path to a market through a mill on the basis of the following variable cost for each of the network links.

Variable cost = hauling cost + maintenance cost. (Equation 1)

Step 2. Iteration = Iteration + 1

If iteration is greater than 10, go to step 5. Recompute variable cost on each link, for each sale, according to the following formula:

Variable cost = (hauling cost + maintenance cost) = Equation (1) + (construction cost + reconstruction cost)/traffic flow

where traffic flow = traffic volume on the link from last iteration, if it is greater than 0; or current timber sale volume, otherwise

Step 3. Generate a minimum path for each timber sale on the basis of the new variable cost for the links.

Step 4. Is the traffic volume from all timber sales on each link of the network for the current iteration equal to that of the previous iteration? If yes, go to step 5. If no, go to step 2.

Step 5. Terminate algorithm.

The small numerical example below illustrates how the algorithm works. The schematic network is shown in Figure 1. For simplicity, all links are 1 mile in length and with hauling cost of \$10/mi/timber unit. The construction costs for links (1)→(3) and (2)→(3) are \$1,000 and \$10,000, respectively.

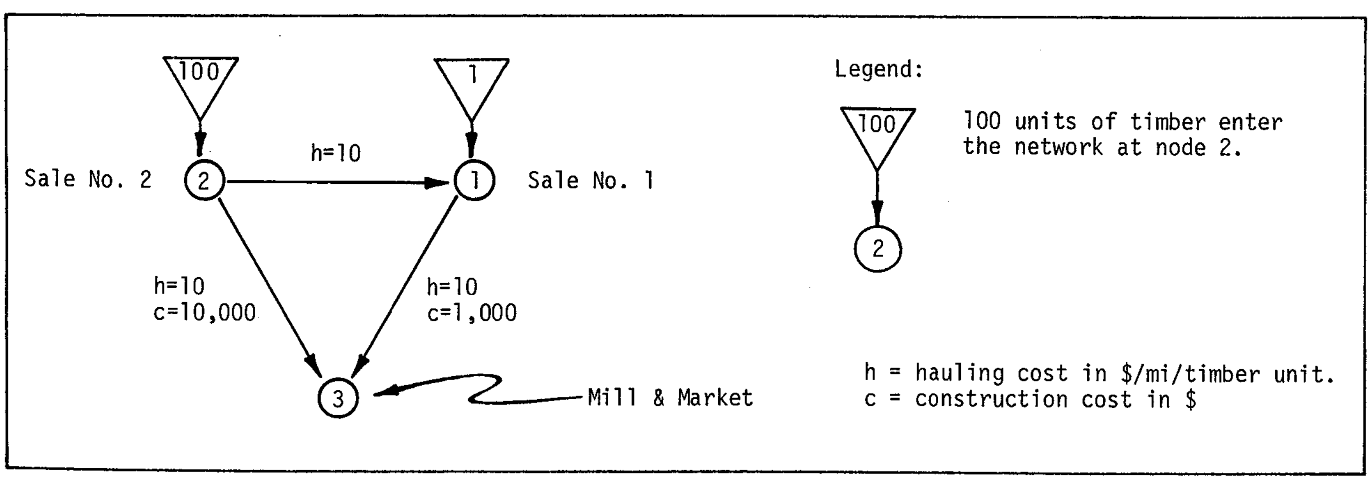


Figure 1. Schematic Network

Iteration 1. Minimum paths for the two sales are generated using hauling cost shown in Figure 1. The solution is shown in Figure 2.

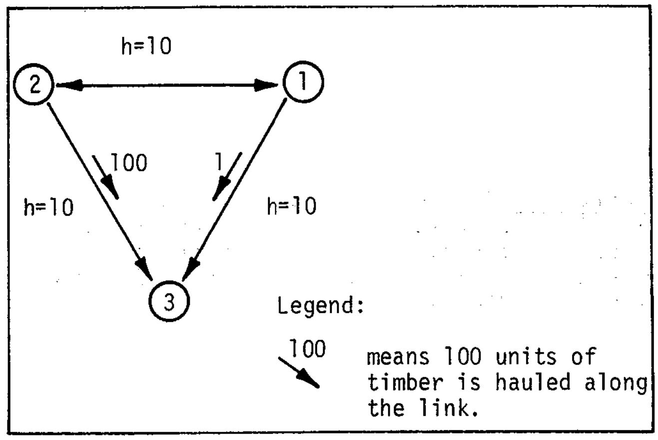


Figure 2. Iteration 1

Iteration 2. The hauling cost on each link is recomputed using equation (1). For example, link (1)→(3) will have the following new hauling cost.

Hauling cost = \$10 + (\$1,000)/1 = \$1,010. The solution of this iteration is shown in Figure 3.

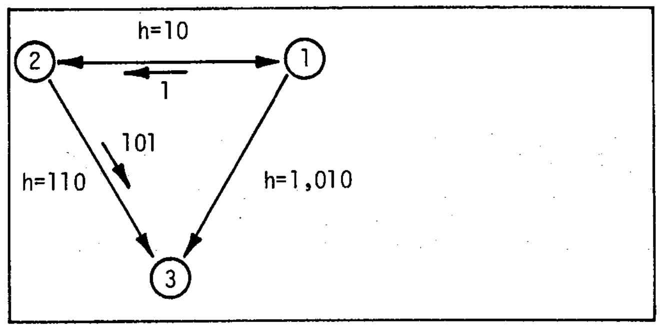


Figure 3. Iteration 2

Iteration 3. Since there was no timber hauling over link (1)→(3), and the timber sales volumes are different for the two sales, the hauling cost used here would not be the same for both sales. For sale No. 1, the hauling cost for (1)→(3) is as follows:

Hauling cost = \$10 + (\$1,000)/1 = \$1,010

However, the hauling cost for (1)→(3) for sale No. 2 is:

Hauling cost = \$10 + (\$1,000)/100 = \$20

The minimum cost paths for the sales are shown in Figure 4(a) and (b). The minimum paths generate a traffic flow pattern shown in Figure 4(c).

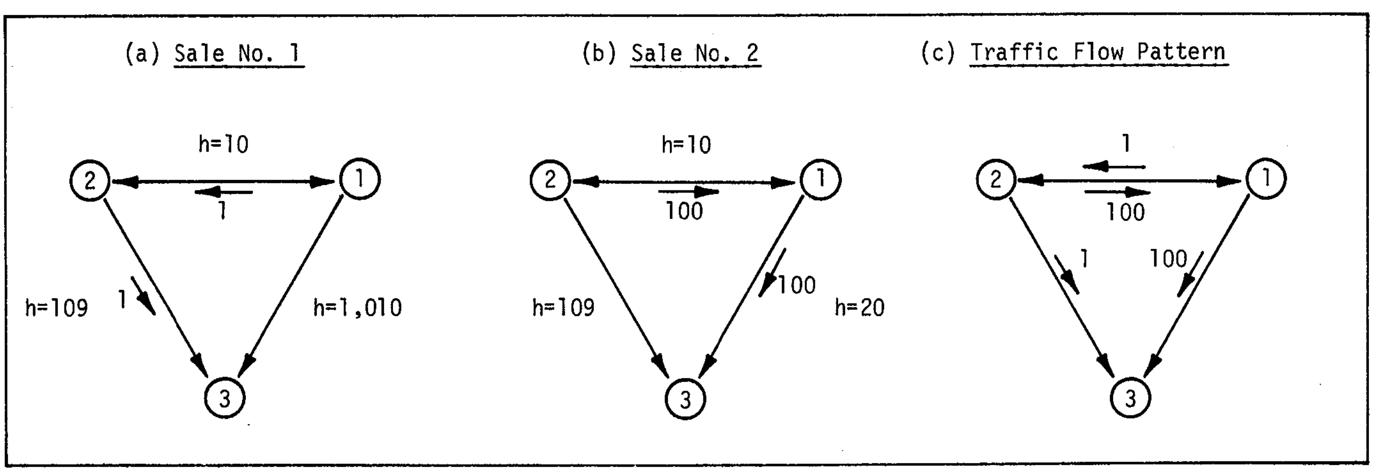


Figure 4. Iteration 3

Iteration 4. We again recompute the hauling costs on the links using equation (1) and then generate minimum cost paths. The result of this iteration is shown in Figure 5.

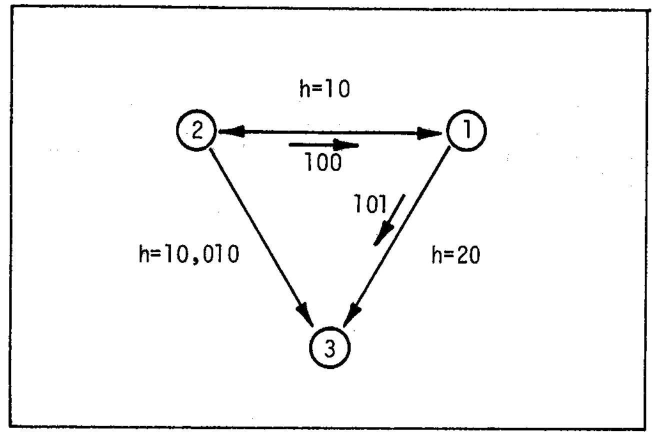


Figure 5. Iteration 4

Iteration 5. As in iteration 3, the hauling cost used here for link ②→③ would depend on the sale under study. The minimum cost paths for this iteration are shown in Figure 6(a) and (b). The resulting traffic flow pattern is shown in Figure 6(c). Since the traffic on each link for this iteration is the same as in iteration 4, the heuristic algorithm terminates.

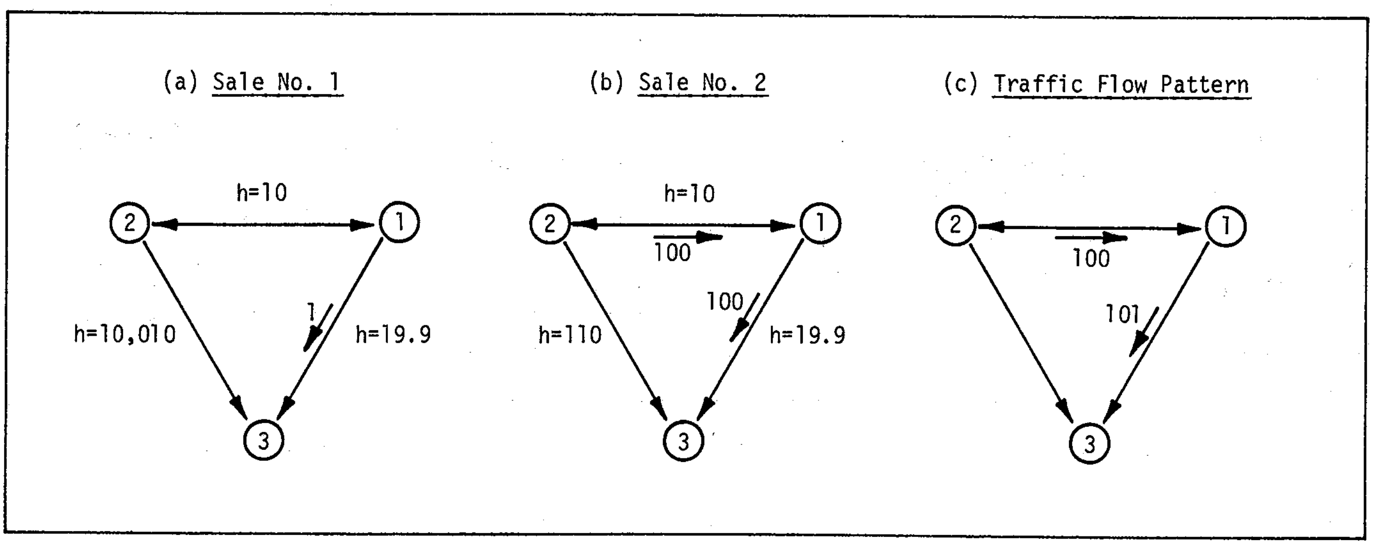


Figure 6. Iteration 5

EMPIRICAL EVALUATION

The behavior of the proration heuristic algorithm is studied by means of a series of small hypothetical problems.

Problem 1. The triangular network shown in Figure 7 is used. All links are 1 mile in length.

The traffic pattern of the solution is shown in Figure 7. The solution value is $220. The optimal solution is for timber sales to use paths ①→②→③ and ②→③. The optimal solution value is $180. In this case, the MINCOST solution value is (40/180) x 100 = 22% higher than the optimum.

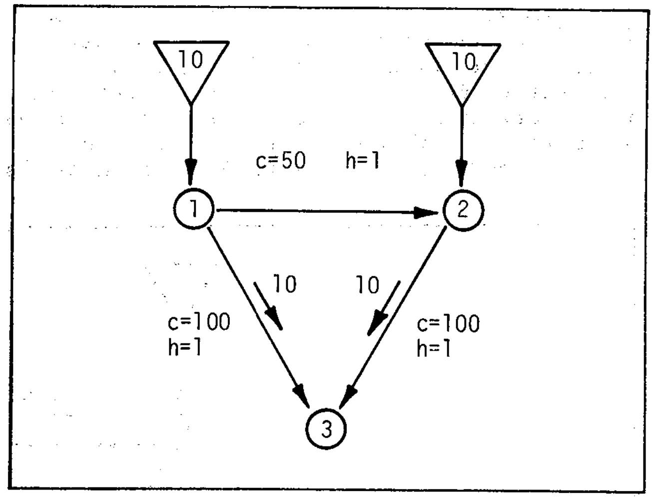


Figure 7. Problem 1

Problem 2. In trying to force the solution to select the path ①→②→③ in problem 1, we increased the construction cost on each link by 10 times. However, the solution traffic pattern remained the same as in problem 1. The deviation of this solution from the optimum is (($2,020-$1,530)/$1,530) x 100 = 32%. A review of the algorithm indicates that the solution is insensitive to the construction cost assigned to link ①→②. The MINCOST solution for a case where no construction cost is assigned to link ①→② is shown in Figure 8. The solution shown in Figure 8 is (($2,020-$1,030)/$1,030) x 100 = 96% higher than the optimum.

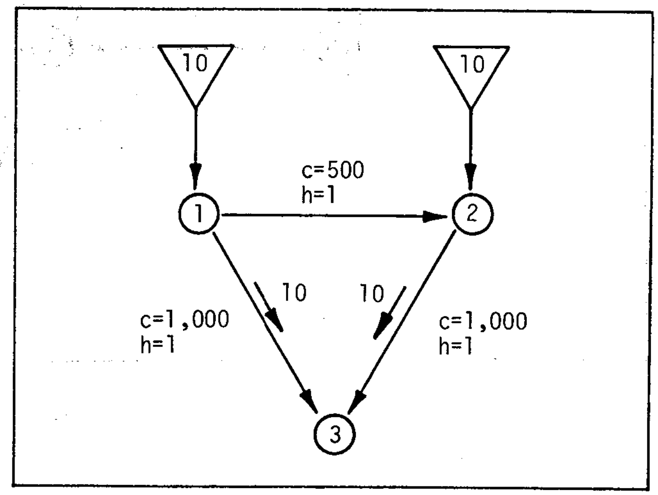


Figure 8. Problem 2

Problem 3. The triangular network is used again, but with construction costs assigned in such a way that would make the path ①→②→③ more attractive than in problem 1. The solution of this problem is shown in Figure 9. This solution is (($1,520-$1,030)/$1,030) x 100 = 48% higher than the optimum.

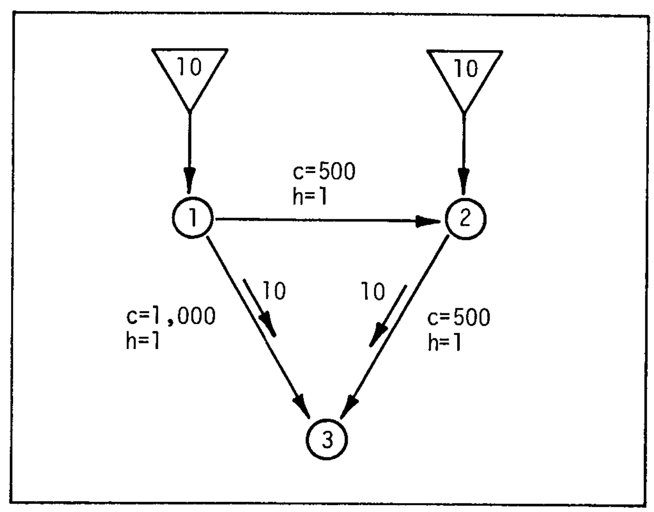


Figure 9. Problem 3

Problem 4. A network constructed from stacking two triangles is used to determine if the solution traffic pattern of earlier problems persists in a more complex network. The network and the MINCOST solution are shown in Figure 10. The MINCOST solution value is $4,060 which is (($4,060-$3,100)/$3,100) x 100 = 31% higher than the optimum. The traffic pattern remained the same when the timber sale volumes at nodes 5 and 6 were changed to 5 units. We can see that the traffic pattern here follows those of problems 1 through 3.

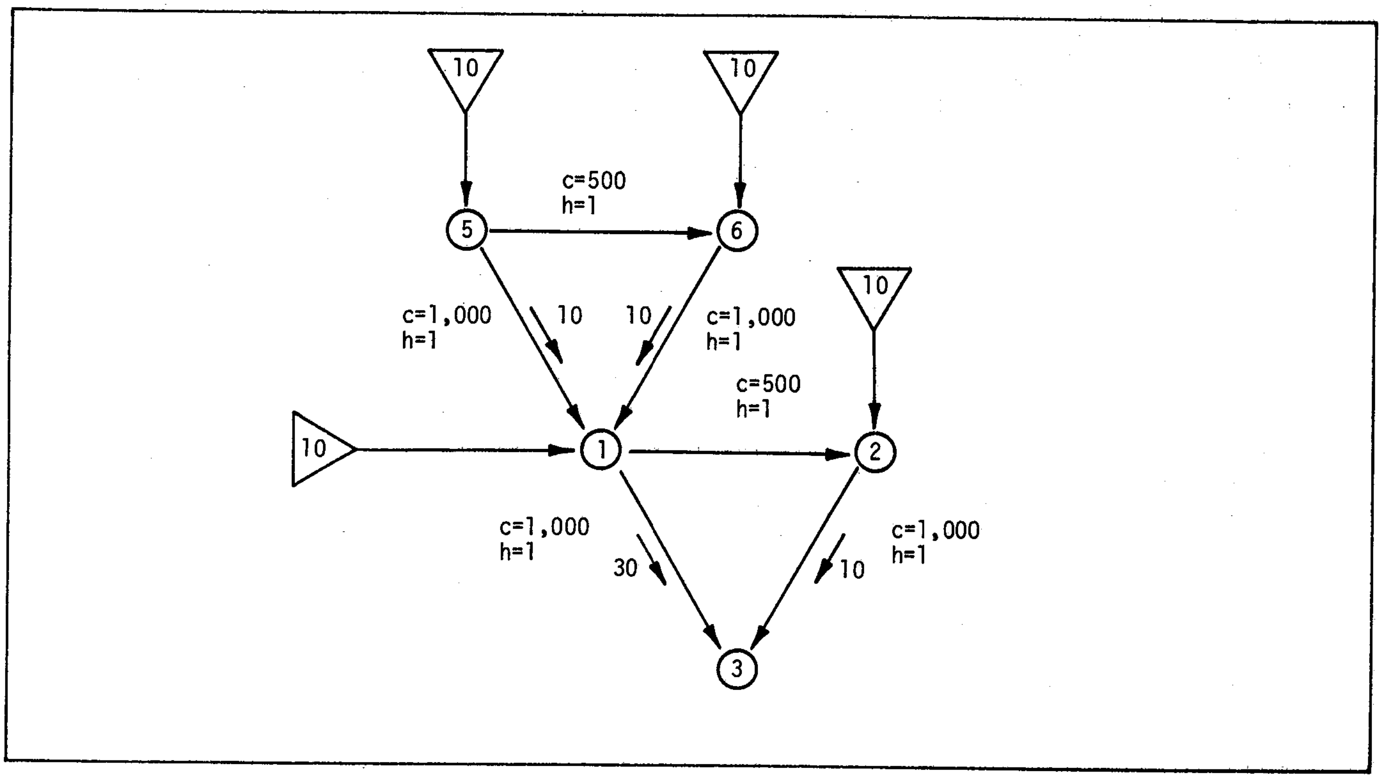


Figure 10. Problem 4

<u>Problem 5</u>. A network similar to the one used in problem 1 is used here, except that flow between nodes 1 and 2 is permitted in either direction. The solution for this problem is shown in Figure 11. The MINCOST solution value of $2,020 coincides with the optimal solution.

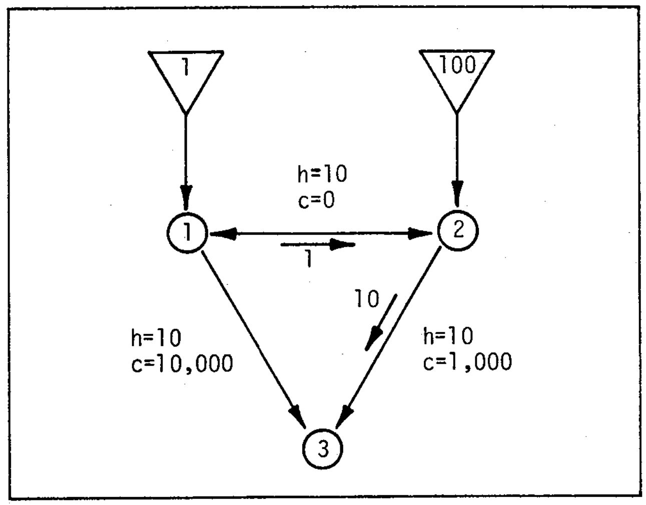


Figure 11. Problem 5

<u>Problem 6</u>. The timber sales volumes of problem 5 are revised to investigate the sensitivity of MINCOST to timber volumes. The MINCOST solution and the network used are shown in Figure 12. MINCOST obtained the optimal solution value of $110,020.

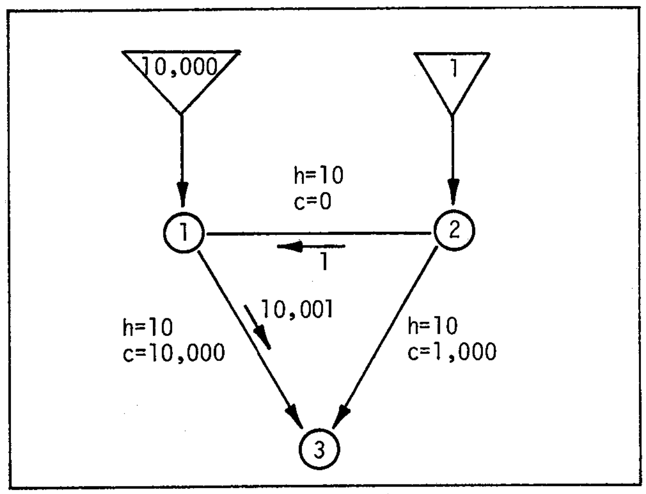


Figure 12. Problem 6

<u>Problem 7</u>. The network shown in Figure 13 is used to test whether MINCOST would select a combination of paths to permit sharing of a construction link by both timber sales. The MINCOST solution of $10,000 corresponds to the optimal solution.

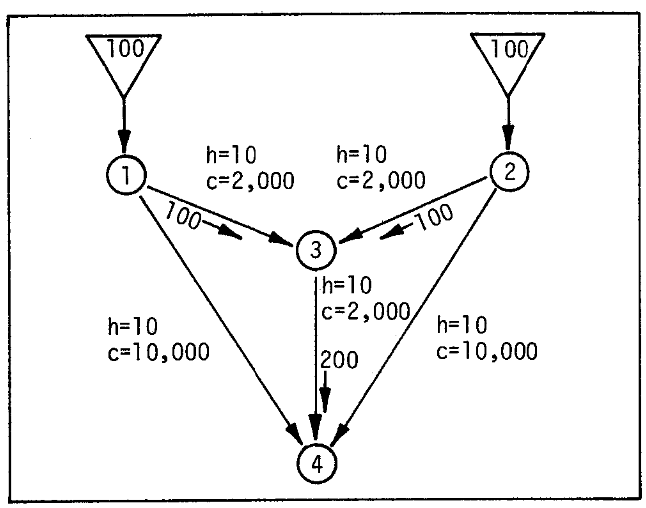


Figure 13. Problem 7

Problem 8. The network shown in the Region 1 MINCOST User's Guide is employed to check the performance of MINCOST on a slightly more realistic network. The network characteristics are summarized in Table 1 below.

The MINCOST solution is shown in Figure 14. Its solution value is $511,872. The optimal solution is shown in Figure 15, which has a solution value of $506,944. Therefore, for this problem the MINCOST solution is within 1% of the optimum. Note that, except for replacing link ③→④ by ③→⑦ in the optimal solution, the remaining networks are the same for the two solutions.

CONCLUSIONS

From the preceding examples, we can see that the MINCOST solution may be the optimum or very far from it. It is not obvious for what network characteristics we can expect a good solution or a bad one. More empirical evaluation of MINCOST using larger and more realistic Forest Service network problems is underway. A theoretical analysis of the proration heuristic algorithm and comparison of MINCOST with other available network analysis procedures will be conducted in the near future.

It is clear, from the examples that, until more is known about the quality of the solution produced by MINCOST, the solution should not be accepted blindly.

Table 1.--Network Characteristics

Link ID		Length (Mile)	Construction Cost ($)	Haul Cost Per Mile ($)	
Node	Node			Forward	Backward
1	2	4.7	38,200	---	1.31
1	4	8.2	68,400	1.31	---
1	5	3.8	61,300	0.91	---
2	3	4.2	27,800	---	1.31
2	4	3.6	50,000	0.91	---
3	4	4.1	32,500	0.91	---
3	7	4.9	72,700	0.71	---
4	5	5.0	50,000	0.91	0.91
4	6	6.2	---	0.51	---
5	6	2.0	32,500	0.71	---
5	8	6.2	---	0.51	---
6	7	2.5	50,000	0.91	0.51
6	8	7.1	28,000	0.51	---
7	8	8.2	---	0.41	---
7	10	11.7	---	0.51	---
8	9	8.7	---	0.31	---
8	10	28.2	---	0.41	---
9	11	16.7	---	0.31	---
10	11	0.0	---	0.0	---

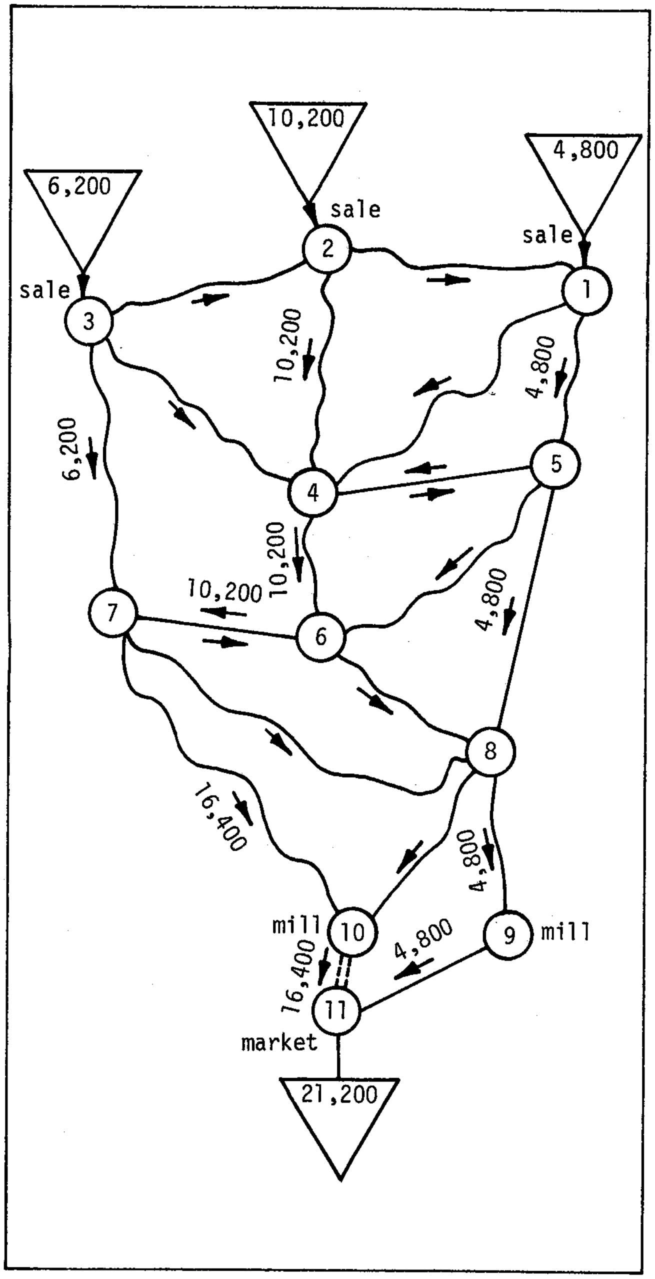


Figure 14. Schematic Layout of Big Creek Network and MINCOST Solution (Not to Scale)

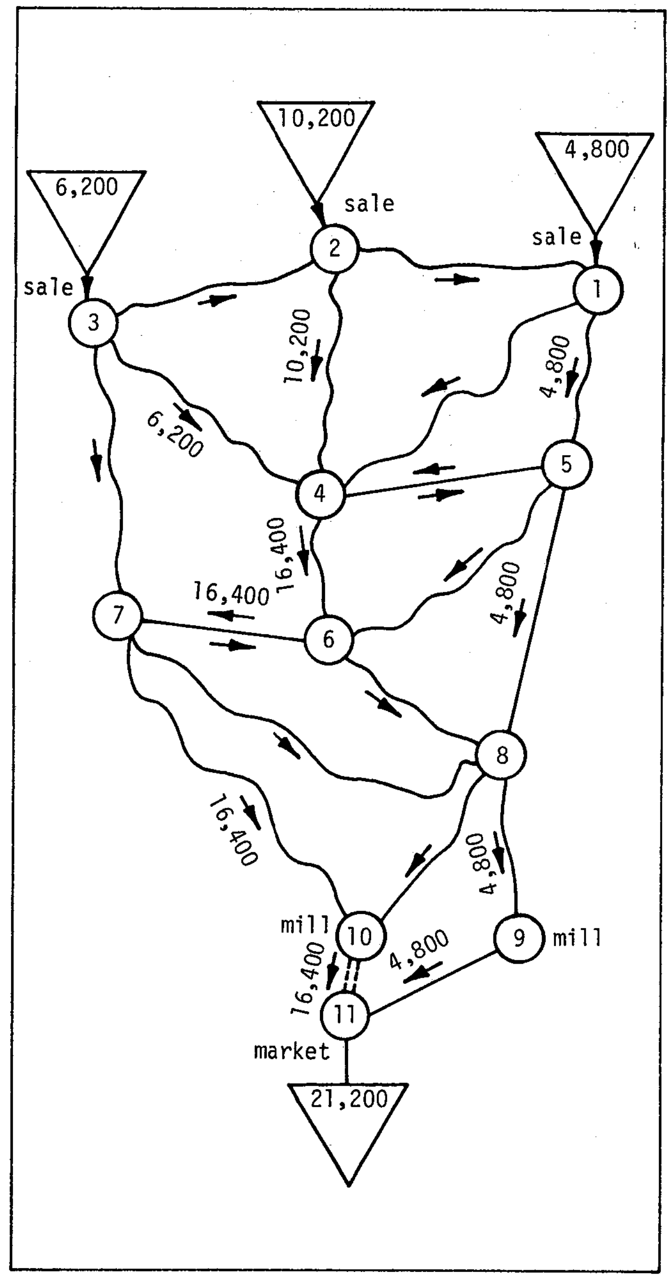


Figure 15. Schematic Layout of Big Creek Network and Optimal Solution (Not to Scale)

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