5. Low-Volume Roads. TRB, Special Rept. 160, 1975, 396 pp.
6. J. Rolt. An Investigation into Road Deterioration in Kenya. In Low-Volume Roads, TRB, Special Rept. 160, 1975, pp 311-327.
7. J.F. Gomez and C.H. Oglesby. A Proposed Approach to Setting Road Maintenance Levels for Forest Roads. In Low-Volume Roads, TRB, Special Rept. 160, 1975, pp. 378-384.
8. W.G. Paterson, H.W. McFarlane, and W.J. Dohaney. Forest Road Classification in Eastern Canada. In Low-Volume Roads, TRB, Special Rept. 160, 1975, pp. 288-295.
9. J.E. Sheflin. Good Roads Do Cost Less. Rural and Urban Roads Magazine, Oct. 1980.
10. C.H. Oglesby and M.J. Altenhofen. Economics of Design Standards for Low-Volume Rural Roads. NCHRP, Rept. 63, 1969, 93 pp.

Simplified Cost-Estimation Method for Low-Volume Roads

THOMAS A. DURSTON AND FONG-LIEH OU

A reliable and fast response method for route alternative analysis is becoming a pressing need as cost-effectiveness becomes a more important factor for low-volume roads. A simplified method for low-volume-road cost estimation is presented. The method consists of estimating various quantities: excavation, clearing, grubbing, seeding, ditch relief culverts, drainage crossings, and surface rock. It is sensitive to design standards and can be used to evaluate various alternatives effectively. A program called ANALYTICAL ROAD COST has been written for the HP41C calculator and is very convenient for making cost-effective analysis. Compared with other methods of cost estimating, the program generally offers greater speed, accuracy, and/or flexibility in choice of design standards. The flexibility and precision inherent in the program provide very refined comparisons of alternative projects. The results obtained by applying the proposed estimation method to four roads were satisfactory. Its estimates were comparable with that made by the engineer after the completion of the design. The method has been adopted by the Gifford Pinchot National Forest in Washington State as a primary tool for cost estimation and can be applied to other low-volume-road systems outside forest lands.

In the early stages of transportation planning, route selection requires quantity and cost estimates for economic analysis. The accuracy of these estimations can be a vital factor in choosing the most economical route. However, accurately estimating road construction costs may be an involved and time-consuming process. Because high construction cost is increasingly becoming a major concern in low-volume roads, the development of an efficient and quick response method for estimating construction costs with higher accuracy and less time commitment is a pressing need. This need is confronted by the Forest Service, U.S. Department of Agriculture, which constructs more than 7000 miles (11 270 km) of new roads annually.

Traditionally in the Forest Service, preliminary construction costs have been estimated by two different approaches. The first and most common approach has been to compile the engineers' estimates for several recent construction contracts. In this approach, the previous cost estimates are grouped into categories based on average ground slope, and a total cost per mile is assigned to each category. The second approach has been to estimate construction quantities and apply unit costs. Quantities have been computed by hand by using simplified mathematical or graphical methods or have been taken from tables and nomographs. However, traditional cost-estimating methods have either been insensitive to variation in design standards or terrain or both, or they have been cumbersome and time consuming to use.

In order to overcome the shortcomings of traditional estimation methods, engineers of the Willamette National Forest in Eugene, Oregon, developed a computerized estimation method based on semi-empirical quantity estimates and a cost matrix. In this method, a construction quantity matrix was constructed by computing quantities based on the designer's aid program (1) for 17 preselected subgrade templates on 8 slope classes applying a set of adjustment factors derived from local experience. Unit costs vary for different slope classes and brush stocking levels. The estimation procedure is embodied in a computer program called Road Cost (which was developed and published by engineers at the Willamette National Forest).

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

The purpose of this paper is to develop a simplified analytical method for estimating costs of low-volume roads by using a program written for the HP41C calculator. The analytical method overcomes the problems of flexibility and transferability. The applicability of the method was demonstrated by several case studies in the Gifford Pinchot National Forest in Washington State. The results of these studies were compared with estimates made by a traditional approach and with the actual quantities and costs as computed in the design.

METHODOLOGY

The primary objective of the proposed cost-estimation approach is to develop a calculating procedure that can be applied to various types of roads, including single-lane roads with and without turnouts and multiple-lane roads. The basic approach is based on generating a typical template that is assumed to be uniform except at drainage crossings. Design assumptions are patterned after those made in the Forest Service road design system (1). Because the single-lane road with turnouts is the basic type of low-volume road on forest land, the cost-estimation procedure was developed according to its physical structure. The algorithm computes quantities and costs based on single-lane and turnout road widths and the percentage of road in turnouts. Quantities and costs may also be calculated for double-lane roads or single-lane roads without turnouts by specifying no turnouts. Quantitites considered in the proposed procedure are excavation, haul, clearing, grubbing, seeding, ditch relief culverts, drainage crossings, surface rock, construction surveying, and mobilization.

Excavation quantities are computed based on a typical full-bench or self-balanced section. The algorithm also considers the excavation volume necessary to construct the through fills specified in the drainage-crossing subroutine. The soil compaction factor is treated as a variable in the self-balanced-section estimation. The typical sections and the variables used are shown in Figures 1a and b. The computation of earthwork volume is accomplished by the following formulations.

For estimating the balanced-section excavation volume (2):

$$V_b = (5280/27)A_1 L \quad (1)$$

where

V_b = balanced-section excavation volume (yd^3),
A_1 = cut end area in balanced sections (ft^2) = $(1/2)(D_c)(W/2 + B)$,
L = length of road segment (miles),
D_c = cut depth = $(W/2 + B)/(1/S - S_c)$,
W = subgrade width (ft),
B = horizontal distance (ft) from centerline to daylight point = $(W/2)(\{(1/S - S_c)/[(1/S - S_f)(1 + C)]\}^{1/2} - 1) \div (\{(1/S - S_c)/[(1/S - S_f)(1 + C)]\}^{1/2} + 1)$,
S = ground slope (decimal percentage),
S_c = cut slope ratio,
S_f = fill slope ratio,
C = soil compaction factor = $(A_f - A_1)/A_1$,
A_f = end area of fill (ft^2) = $(1/2)(D_f)(W/2 - B)$, and
D_f = fill depth (ft) = $(W/2 - B)/(1/S - S_f)$.

For estimating the full-bench excavation volume,

$$V_f = (5280/27)A_2 L \quad (2)$$

where

V_f = full-bench excavation volume (yd^3),
A_2 = cut end area in full-bench sections (ft^2),
A_2 = $(1/2)WD_b$, and
D_b = $S_c W/(1 - SS_c)$.

As shown in Figure 2, the clearing is to run from a specified upper limit to the toe of the fill. The clearing area may be estimated by

$$A_c = W_c L/8.25 \quad (3)$$

where

A_c = clearing area (acres),
W_c = $C_1 + S_c D_c + W + S_f D_f$, and
C_1 = distance of clearing beyond the top of the cut (ft).

The grubbing area is illustrated in Figure 3. Grubbing is required from the top of the cut to the toe of the fill if fill depth is less than or equal to 2 ft (0.61 m) or to the point where fill depth exceeds 2 ft on larger fills. The grubbing area for these two cases can be computed by

$$A_g = W_g L/8.25 \quad (4)$$

where A_g is the grubbing area (acres), and W_g equals $W_c - C_1$ if D_f is less than or equal to 2 ft, or equals $(D_c + 2)/S$ if otherwise.

Seeding area is taken to be the area of the cut and fill banks, as shown in Figure 4. The seeding area may be estimated by

$$A_s = (W_1 + W_2)L/8.25 \quad (5)$$

where

A_s = seeding area (acres),
W_1 = $D_c/\cos(\tan^{-1}S_c)$, and
W_2 = $D_f/\cos(\tan^{-1}S_f)$.

Note that clearing and grubbing areas are a horizontal measure, while seeding area is a slope measure.

This study assumes that ditch relief culverts are installed at given intervals. Culvert length may be estimated for the three different situations shown in Figure 5. Figures 5a and b show two different approaches for calculating culvert length in a balanced section. The culvert length in Figure 5a is computed from the ditch line to the toe of the fill where no down drain is required. The maximum allowable gradient in a culvert is assumed to be 30 percent. If the computed gradient of the culvert exceeds 30 percent, it is assumed that the gradient will be reduced to 30 percent and a down drain will be installed. The down-drain length is estimated

Figure 1. Excavation volume.

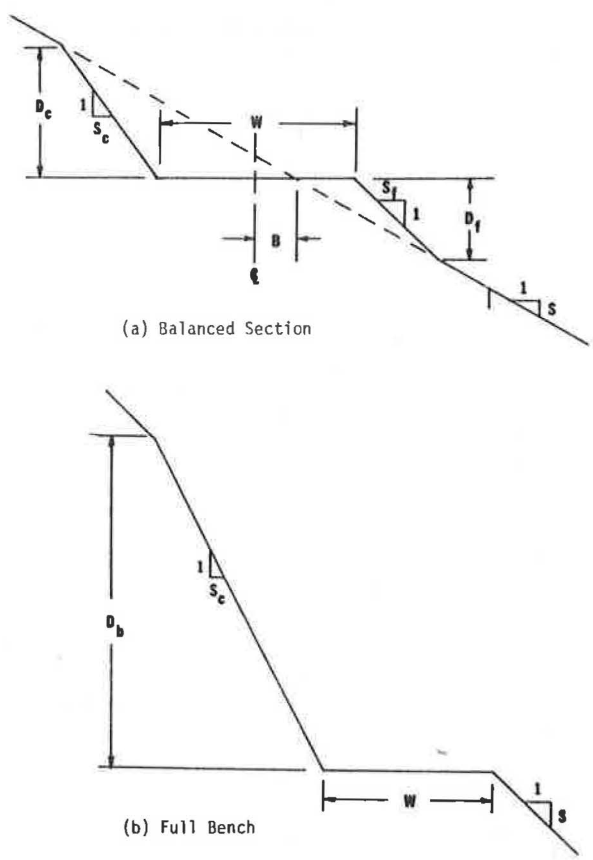


Figure 2. Clearing area.

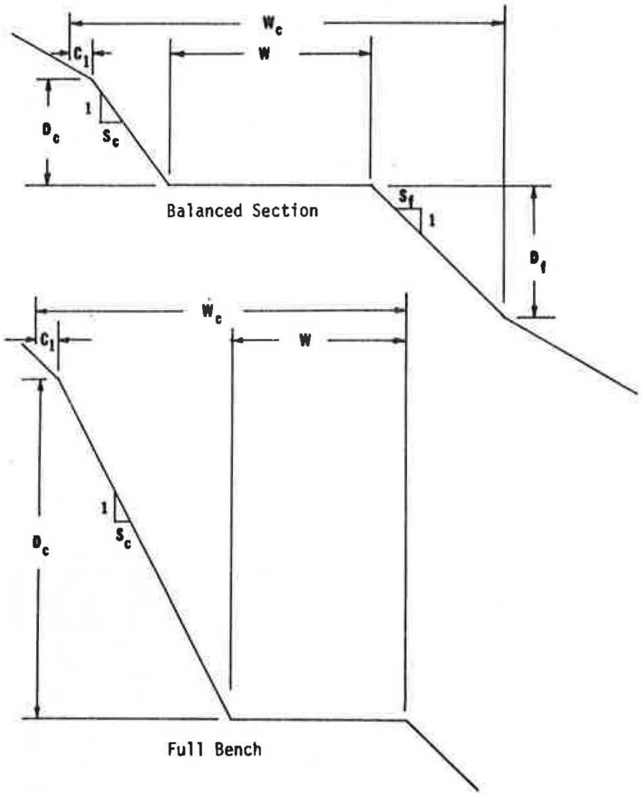
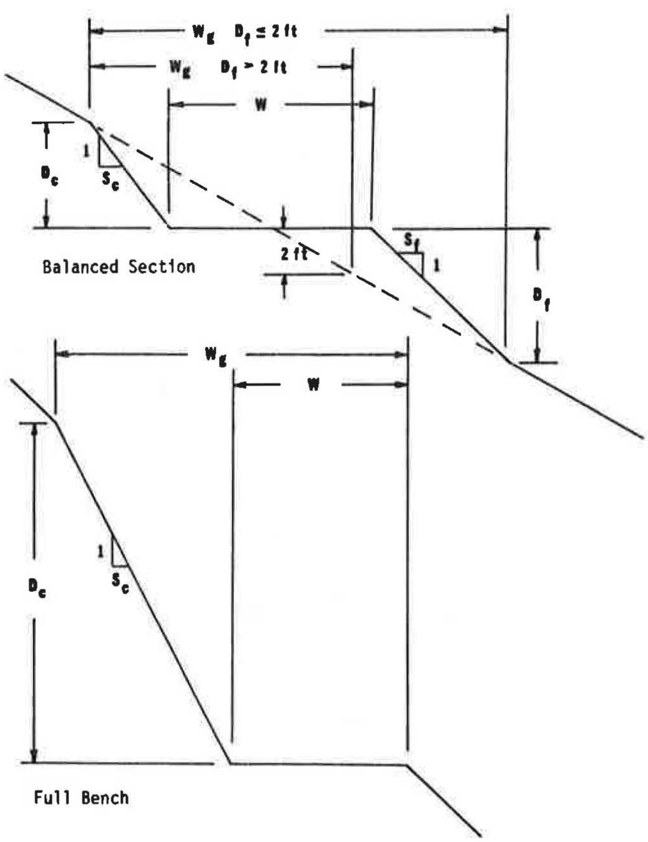


Figure 3. Grubbing area.



according to the sketch shown in Figure 5b. When a down drain is required, an additional cost must be added for elbows, anchors, and energy dissipators. Figure 5c shows a sketch of the typical culvert for a full-bench section. The equations for computing the length of culvert for the three cases are listed below. For a balanced section without down drain,

$$L_p = [(W + D_f S_f)^2 + D_f^2]^{1/2} + 2 \quad (6)$$

Figure 4. Seeding area.

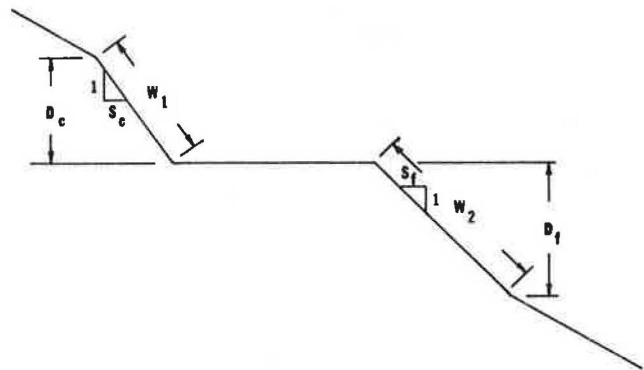


Figure 5. Ditch relief culverts.

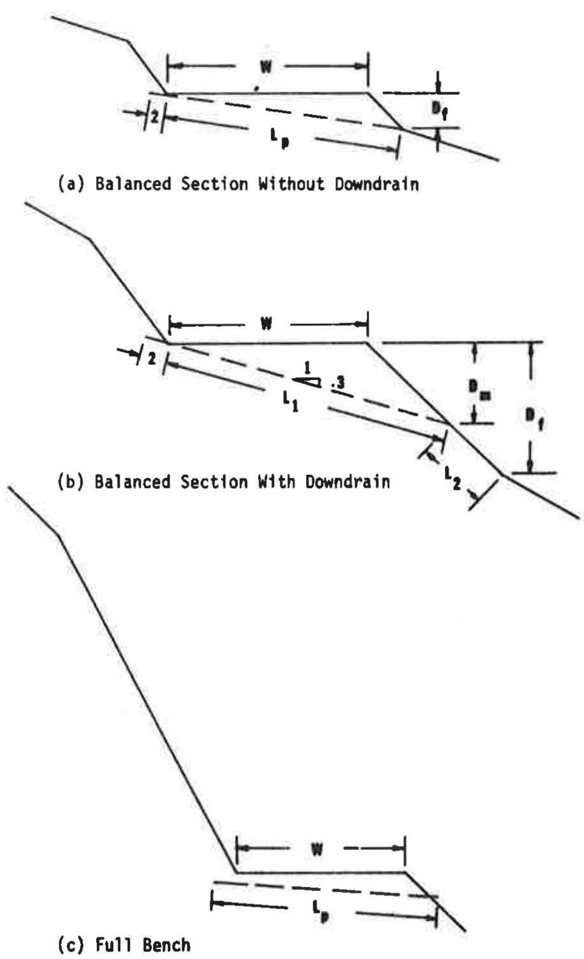


Figure 6. Drainage crossing.

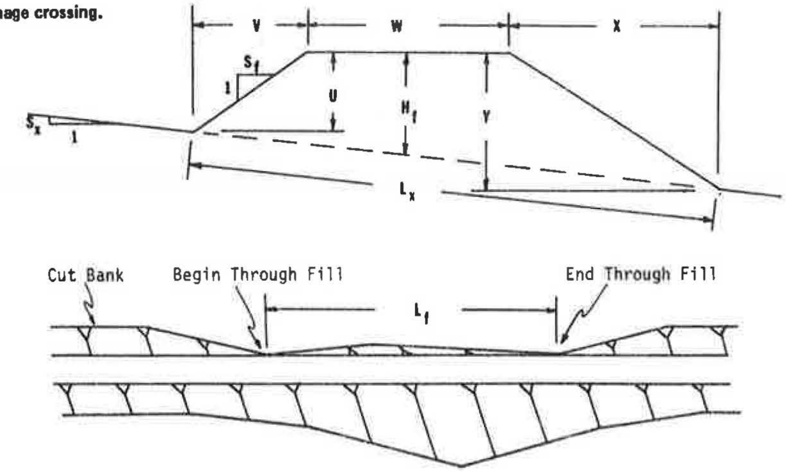
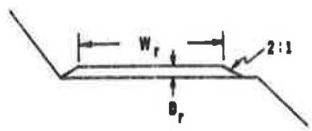


Figure 7. Surface rock volume.



For a balanced section with down drain,

$$L_p = [D_m^2 + (W + S_f D_m)^2]^{1/2} + (D_f - D_m)/\sin[\tan^{-1}(1/S_f)] + 2 \quad (7)$$

For a full-bench section,

$$L_p = W + 4 \quad (8)$$

where L_p = length of culvert (ft) and $D_m = 0.3W/(1 - 0.3S_f)$.

Figure 6 is a sketch of the typical drainage crossing. It is assumed that additional excavation is required to construct through-fill drainage crossings if the typical section is self-balanced, but no additional excavation is required in full-bench sections. The additional earthwork is assumed here to be the through-fill volume adjusted for compaction. The through-fill excavation volume for drainage crossings is computed by Equation 9, while the culvert length is estimated by Equation 10:

$$V_x = \{(1/3)[YV + YW + U(W + X)] L_f\}/[(1 + C)(27)] \quad (9)$$

$$L_x = [(V + W + X)^2 + (Y - U)^2]^{1/2} \quad (10)$$

where

V_x = excavation volume (yd^3),
$U = H_f - (W/2 + V)(S_x)$,
$V = [S_f H_f - (W/2) S_x S_f]/(1 + S_x S_f)$,
$X = [S_f H_f + (W/2) S_x S_f]/(1 - S_x S_f)$,
$Y = H_f + (W/2 + X) S_x$,
S_x = gradient of drainage (decimal percentage),
H_f = height of fill at centerline (ft),
L_f = length of through fill (ft), and
L_x = length of the drainage-crossing culvert (ft).

Finally, based on the sketch in Figure 7, the volume of surface rock may be estimated by

$$V_r = (2W_r + D_r/6) D_r L(5280/324) \quad (11)$$

where

V_r = volume of surface rock (yd^3),
D_r = depth of rock (in),
W_r = top width (ft), and
L = length (miles).

The above equations for various quantities were integrated into a computation procedure contained in a program entitled ANALYTICAL ROAD COST (ARC) written for the HP41C calculator. The program allows the user to specify full-bench section or self-balancing section, soil compaction factor, ground slope, length, earthwork haul distance, rock haul distance, cut slope and fill slope ratios, aggregate depth, distance between culverts, road widths, distance from top of cut to clearing limit, unit costs, and, on through-fill drainage crossings, the length of the through fill and the depth at the drainage. With this flexibility, the user may test the sensitivity of each factor and formulate various project alternatives. If a project consists of several road segments with different characteristics, the program can accumulate quantities and costs and print the project total.

MODEL VALIDATION

In order to check the accuracy of the ARC program, a sample of four typical roads on the Gifford Pinchot National Forest was selected for case studies. The result of each application was compared with a traditional method of estimation and the engineer's estimate from the design quantities.

In these four case studies, input data for the road cost estimates were taken from survey and design notes. Slope data were taken from preliminary line (P-line) survey notes. The roads were divided into segments that had roughly the same ground slope. These segments were generally 0.3-0.5 mile (0.48-0.81 km) in length. Road design standards and drainage-crossing fill heights and lengths were taken from the design. Unit costs were taken from the engineer's estimates. Note that the data obtained in this way are more accurate than that usually available to transportation planners, so the ARC estimates are probably more accurate in this case than usual. The same data base was also used for the traditional method estimates, however, and should have reduced the error for these estimates as well.

In this study, the traditional approach consisted of using the average of previous engineer's estimates. The engineer's estimates for 1981 construction contracts were compiled, and the average per mile costs for five slope classes were developed. These costs, which were used at zone II A, Gifford Pinchot National Forest (in 1981), are given in the

Table 1. Comparison of cost and quantity estimates for major items.

Item	Road 4205.025	Road 4207.000	Road 4207.018	Road 4207.023
Length (miles)	0.70	2.55	1.77	0.80
Total cost				
Engineer's estimate ($)	85 245	277 762	190 795	134 676
ARC ($)	73 167	262 046	165 644	123 972
Error (%)	-14	-6	-13	-8
Conventional method ($)	93 968	469 160	302 859	185 069
Error (%)	+10	+69	+59	+37
Excavation volume (yd^3)				
Engineer's estimate	11 158	46 545	27 118	20 760
ARC	10 571	50 098	23 933	21 002
Clearing area (acres)				
Engineer's estimate	4.40	14.30	9.74	5.51
ARC	3.41	11.25	7.07	3.59
Seeding area (acres)				
Engineer's estimate	4.25	16.33	10.25	5.31
ARC	1.94	7.07	3.99	2.37
Haul (station yd^3)				
Engineer's estimate	26 558	279 946	134 574	69 351
ARC	16 996	180 746	109 227	89 816
Aggregate (yd^3)				
Engineer's estimate	1263	0	0	0
ARC	1109	0	0	0
All drainage costs ($)				
Engineer's estimate	16 120	50 204	26 938	27 097
ARC	12 051	47 910	35 543	32 674

Notes: All costs expressed in 1982 U.S. dollars.
1 mile = 1.6 km, 1 yd^3 = 0.765 m^3, 1 acre = 0.405 hm^2, and 1 station = 30.48 m.

table below (note that 12 percent/year should be added to the costs per mile to account for inflation, and 1 mile = 1.6 km):

Side Slope (%)	Cost per Mile ($000s)
0-30	80
30-40	105
40-50	142
50-60	204
≥60	≥237

As recommended, a 12 percent inflation adjustment was made to estimate costs for construction in 1982. A similar inflation factor is included in the unit costs for ARC estimates and the 1981 engineer's estimates.

Based on the given data, cost estimates for four roads were made by ARC and the conventional approach. These estimates, along with the engineer's estimates, are given in Table 1. Comparing estimates made by ARC and the conventional approach with the engineer's estimates indicate that ARC can make a more accurate and consistent estimate. The estimate error for ARC is less than 15 percent, while the estimate error for the conventional method could amount to nearly 70 percent. However, there is a tendency that ARC made underestimates while the conventional approach resulted in overestimates.

The error in the traditional method estimates was greatest for roads 4207.000, 4207.018, and 4207.023 because these roads were designed with lower-than-average standards, including native surface and steeper cut banks. The error in the ARC estimates was more uniform, since the variation in roadway template was accounted for in the estimation of quantities.

The sources of the underestimate in ARC can be inferred from the quantities and costs given in Table 1. Generally, good agreement is found between the two in the excavation cost. ARC overestimated the excavation quantity on road 4207.000 by 7 percent and on road 4207.023 by 1 percent, but underestimated it on road 4207.018 by 12 percent and on road 4205.025 by 5 percent. The discrepancy is due, in part, to variations in terrain and the designer's choice of vertical and horizontal alignment. Generally, excavation volumes are higher than those computed for a true self-balanced section due to through cuts and fills. The addition of excavation volume computed by ARC for through-fill drainage crossings may add up to more or less than the earthwork actually designed. The roads in this study are contour-fitting roads with an average alignment factor [average horizontal curve radius (in feet) divided by number of horizontal curves per mile] of 5.3. Higher excavation volumes would be expected on roads with better alignment. Also, staked road widths vary from nominal road widths due to slough widening, curve widening, and daylighting of cuts. In using ARC, rule-of-thumb adjustments were made to the nominal widths. These adjustments were developed from Gifford Pinchot National Forest experience. Soil compaction factors were also developed from local experience. The correct choice of a soil compaction factor is important for an accurate estimation of quantities when using ARC. Higher soil compaction factors may be used to model the effect of better alignment.

The greatest discrepancy between ARC and engineer's estimates is in the clearing and grubbing items. The ARC estimate of clearing area is consistently low because it does not account for log-decking areas and burn bays. The error averages 28 percent and is considered acceptable, since the discrepancy in clearing and grubbing costs averaged only 5 percent of total project costs and because log-decking area and burn-bay acreage cannot be predicted in a generalized, systematic way.

The seeding acreage estimate is also low because ARC assumes seeding only on cut and fill banks, but the designs called for seeding of the entire roadway on the 4207 roads. In general, it is more correct to assume, as ARC does, that the roadbed is not seeded. Also, the ARC estimate neglects the log-decking and burn-bay acreage.

Haul costs were also difficult to predict due to variations in terrain and alignment. In using ARC, rule-of-thumb averages were used for haul distances. The errors in the haul quantities estimated by ARC were -36, -35, -19, and +30 percent, respectively, and the errors in haul cost fall into a range from -2 to +4 percent of the total road cost.

Generally, the ARC program made more accurate cost estimates than the traditional approach. In particular, ARC was more responsive to variation in design standards.

CONCLUSIONS

A quick turnaround cost-estimation method has been developed for use in planning low-volume roads. The method has been presented in a program written for the HP41C calculator. Its applicability was demonstrated by four case studies. The results of the studies indicated that the developed procedure can make more accurate and consistent estimates than a conventional approach. Because the procedure allows the examination of various alternatives conveniently, the transportation planner may use it to plan a more cost-effective low-volume-road system under pressing deadlines.

REFERENCES

1. Engineering Computer Application Handbook. Forest Service, U.S. Department of Agriculture, April 1981.
2. S.K. Smith. The Use of a Hand Held Pocket Computer for Timber Road Design. Forest Service, U.S. Department of Agriculture, Six Rivers National Forest, Mendocino, CA, Nov. 1976.