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Estimating the Least Cost Combination Of Cable Yarding And Tractor Skidding For A Timber Sale Area

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Estimated costs of several alternative combinations of access roads and associated tractor skidding and skyline cable yarding areas are analyzed for a 562-acre, mixed conifer watershed in Arizona. Results of this case study are extended into a general discussion of road costs, yarder size, and tractor skidding as they relate to future harvesting opportunities in central and southern Rocky Mountain forests.

Keywords: Cost minimization, logging operations design, yarding costs, tractor logging costs, logging road costs (temporary), skidding costs.

Background

Land managers have indicated that an increasing proportion of future timber supplies must come from sites with slopes exceeding 40%. In the central and southern Rocky Mountains a substantial proportion of the harvestable timber is on such sites. Harvesting this overmature and mature timber is an integral part of adequate resource management and it is essential in achieving other multiple-use benefits. Access, environmental, and economic problems expand with increase in slope. Managers must evaluate different harvesting and site protection alternatives to determine which method — if any — is both economically feasible and environmentally sound.

In a study to define the multiple-use responses of a typical southwestern mixed-conifer watershed, the Forest Service has considered several possible harvest treatments for the South Thomas Creek experimental watershed on the Apache-Sitgreaves National Forest in east-central Arizona (Brown 1976). Water yield response will be tested by cutting marked trees on small areas at 20-year intervals over a 120-year rotation. Subareas of the watershed, defined as Land Response Units (LRU) and identified on the basis

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of tree species, soil type, slope, and aspect, are shown in figure 1. Cutting methods are group selection, shelterwood, and individual tree selection. Each LRU has a particular treatment which will result in different harvest volumes for the initial entry:

Land Response Unit (LRU)	Area	Basal area harvested[3]	Harvest gross volume[4]
	Acres	*Percent*	*Mbf*
1	36	40.5	171.7
2	77	28.7	499.6
3	233	22.3	1497.4
4	159	29.4	1179.9
5	55	23.4	181.5
Total	560[2]	—	3530.1

LRU's 1, 2, and 5a are the steep slope areas which make up 20% of total area and 19% of harvest volume.

Topography is a mix of gentle and steep slopes ranging upward to 55%. Some combination of tractor skidding and cable yarding will be required to harvest trees that are marked for cutting without special regard for harvesting convenience. Several combinations of access roads and associated skidding and skyline yarding areas were analyzed to determine the least costly means of treating the watershed within given prescriptions and environmental constraints. The analytical method employed is a composite of appraisal techniques now used in other areas by the National Forest System. Although specific costs shown in this Note cannot be directly applied elsewhere, the concept of systematic analysis should be applicable elsewhere.

Objective

The objective of this analysis was to compare estimated costs of several alternative yarding and skidding combinations along with associated access roads for the South Thomas Creek watershed. Numerous alternative logging and road systems could be developed for logging this watershed, but six alternative systems were identified for further study after initial screening for both environmental and economic effects.

[2]*An additional 2 acres of meadow on the upper watershed are to be protected from all treatment activity.*

[3]*Personal communication from G. J. Gottfried, Research Forester, Rocky Mtn. For. and Range Exp. Sta., Tempe, Arizona, 1975.*

[4]*From Statistical Analysis of Timber Sale, South Thomas Creek. Southwestern Region, USDA Forest Service, 1975.*

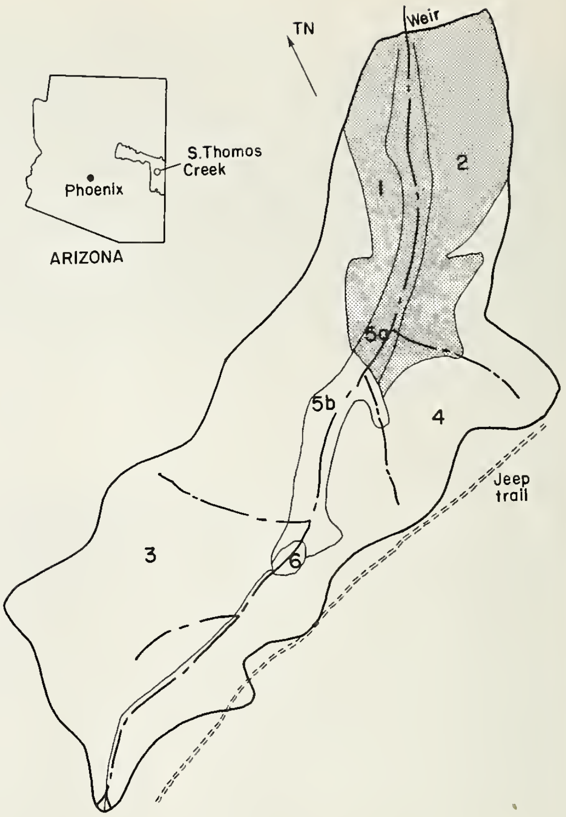

Figure 1.—South Fork, Thomas Creek Watershed Land Response Units (LRU). Shaded section is approximate steep slope area.

Harvest Systems Design

Slope Class Analysis and Road Placement

Inspection of the Thomas Creek topographic map showed general areas of steep and level ground. However, more definitive information was needed on location and extent of areas by percent slope class to locate roads and to designate areas suitable for tractor skidding and skyline yarding.

To satisfy this additional data need, three slope classes were defined on South Thomas Creek: slopes less than 40%; 40% to 50%; and 50% and greater. Each 25-ft contour interval was marked on an overlay according to its slope class. Areas whose slopes were between 40% and 50% and over 50% were interspersed. No large areas fell into either of the two steepest slope classes. Moreover, any part of the watershed designated for cable yarding would necessarily include some areas where slopes are less than 40%.

All South Thomas Creek access roads could be linked to existing haul roads built for an adjacent commercial timber sale. No special problems in road placement were encountered on the flat areas except a 2-acre meadow in the upper part of the watershed that was to be protected from all treatment activity.

Access roads for cable yarding on steep ground should be on benches or breakpoints between steep and relatively flat ground whenever permitted by topography. No flat benches occur in the South Thomas Creek cable logging area, so roads were planned to be on the terrain breakpoint between steep ground and the ridgetop. Midslope roads were designed to follow the least steep slope available but, unavoidably, some areas with over 50% slope were crossed. The location of a road near the creek bottom was high enough above the creek to satisfy National Forest System sedimentation guidelines. Branch roads for the flat ground were also planned.

All alternative road locations were divided into segments for further analysis. Each distinct road segment was identified by a letter and number denoting branch and segment, respectively.

Road segments required for each alternative are shown in table 1. The "A" branch road segments on flat ground are common to all alternatives, as well as some of the "B" and "C" segments. With these road locations, six alternative skidding/yarding combinations appeared to be technically feasible:[5]

A Cable yard from the creek bottom up to the ridgetop roads (B5, B6, D3, D4). Tractor skid extreme upper parts of each ridge down to the roads (B5, B6, D1, D2, D3, D4).

B,C Cable yard both slopes from the creek bottom up to the roads (B5, B7, D3, D4). Tractor skid down to midslope road (B7) on

[5]*There are 31 combinations possible using 1 or more of the listed roads. And some combinations of road locations have more than one skidding-yarding arrangement. For example, a running skyline interlock yarder could yard both uphill and downhill from a midslope road. This option was not actively considered here because of the high yarder cost and convex topography above the probable location of the midslope road.*

Table 1. Estimated road costs for different treatment alternatives

Road segment	Treatment alternatives and initial road segment cost[1]: A	B,C	D	E	F	Segment length	Subsequent reopening, maintenance, closing cost	Road standard
	Dollars					*Ft*	*Dollars*	
A1	497	497	497	497	497	1,360	497	Grade only
A2	746	746	746	746	746	2,040	746	Grade only
A3	1,258	1,258	1,258	1,258	1,258	3,440	1,258	Grade only
B1	1,228	1,228	1,228	1,228	1,228	3,360	1,228	Grade only
B2	293	293	293	293	293	800	293	Grade only
B4	748	748	748	748	748	2,040	748	Grade only
B5	892	892	892	892	892	2,440	892	Grade only
B6	826	—	—	—	—	2,080	826	Grade only
B7	—	14,547	14,547	14,547	14,547	2,640	1,495	Grade, drain, culverts, surfacing
C1	2,400	2,400	2,400	2,400	2,400	2,000	680	Grade, drain, culvert
C2	351	351	351	351	351	960	351	Grade only
C3	2,683	2,683	2,683	2,683	2,683	2,440	891	Grade first 1,200 ft; remainder grade, drain, culverts
C4	—	—	21,696	—	21,696	3,960	2,157	Grade, drain, culverts, surfacing
C5	702	702	702	702	702	1,920	702	Grade only
C6	—	—	220	—	220	600	220	Grade only
D1	238	238	—	238	—	700	238	Grade only
D2	307	307	—	307	—	840	307	Grade only
D3	276	276	—	276	—	800	276	Grade only
D4	3,650	3,650	—	3,650	—	2,800	1,234	Grade, drain, culverts
E1	—	—	—	22,863	22,863	4,080	2,170	Grade, drain, culverts, surfacing
Total road costs	17,095	30,816	48,261	53,679	71,124			

[1]*Includes closure.*

SE-facing upper slope and down to ridge road (D3, D4) on extreme upper NW-facing slope. (Two different size yarders were considered in this alternative.)

D Cable yard up to each midslope road (B5, B7, C3, C4) from the creek bottom. Tractor skid each slope's upper area down to the road (B5, B7, C3, C4).

E Cable yard the upper part of the NW-facing slope to the ridge road (D3, D4). Tractor skid as high as practicable on NW-facing slope to creek bottom road (E1). Tractor skid entire SE-facing slope, the upper part down to "midslope" road (B5, B7), the lower part down to creek bottom road (E1).

F Cable yard the lower part of the NW-facing slope from the midslope road to the creek bottom road (E1). Tractor skid upper part of NW-facing slope down to the midslope road (C3, C4). Tractor skid entire SE-facing slope, the upper part down to the "midslope" road (B5, B7) and the lower part down to the creek bottom road (E1).

Cable Yarding and Tractor Skidding Areas

Once the road network for each alternative was identified on individual overlays, yarding areas were defined. Logs can be decked by conventional wheeled skidders on approximately 80% of the area, but cable yarding should be used for the remaining steep slopes. Cable yarding boundaries depended on access road location and the amount of continuous terrain with slope greater than 40%. Approximate yarder setting and cable corridor locations were based on an assumed total setting width of 150 ft. For yarder locations on the southeast-facing slope, tailspars could easily be located on the opposite slope to gain additional deflection and load capacity. Where settings on the northwest-facing slope were too long for tailspars on the opposite slope, tailspars were planned for the same slope as the yarder. No anchor problems were anticipated, since there are numerous large, deeply rooted ponderosa pines and no major windfall areas on the steep slopes. Landing and log deck locations were adequate in most areas; in tight areas a grapple skidder could swing logs to a more convenient deck location.

All ground not covered by cable yarding would be tractor skidded. Each planned access road would have one or more adjacent log decks. On flat areas, skidders would travel equal distances to roadside decks from both sides of the road. On steeper areas, loaded skidders would travel downhill to the road wherever possible. Estimated average skid distances, stratified for uphill and downhill directions, were computed for each alternative on the basis of overlay map areas.

Cut Timber Volume For Yarding And Skidding Areas

Feasible yarding and skidding area boundaries for each alternative did not coincide with the LRU boundaries, so harvest volumes, available by LRU, were apportioned between the cable yarding area and the uphill and downhill tractor skidding areas. These areas are slightly different for each alternative, resulting in different log volumes to be handled in each case by cable yarding and tractor skidding (table 2).

Appraisal

Road Costs

All road location data were evaluated by personnel of the Apache-Sitgreaves National Forest to estimate costs for each possible road segment (table 1). Their suggested cost estimates were based on the road standards necessary to conform with resource protection requirements developed in an environmental analysis of the proposed watershed treatments.

Road segment costs were estimated for three road standards: graded only; graded and drained with culverts; and graded, drained with culverts, and surfaced. Road closing costs were assumed to be the same for each road standard. Since cost increases as side slope increases, the cost for each road segment was affected by how much of its length fell into each of the three slope classes. For example, road segment A-1, which required grading only, had a total length of 1,360 ft, all on slopes less than 40%. Its total estimated cost was $497 including closure after watershed treatment[6]. However, road segment B-7, requiring grading, drainage, culverts, and surfacing, had a length of 1,400 ft on slopes less than 40%, a length of 440 ft on slopes between 40% and 50%, and a length of 800 ft on slopes greater than 50%. This resulted in a total estimated cost of $14,547, including closure. Total road costs for each alternative were determined by adding costs for all road segments included in that alternative (table 1).

Road costs are large factors in the total cost for roads, yarding, and skidding (table 2). In Alterna-

[6] *All cost estimates, current for late 1975, were estimated to the nearest dollar; however, accuracy to the nearest dollar is not implied.*

tives C, D, and F, total tractor skidding cost remains about the same, total cable yarding cost decreases, yet total cost increases significantly because of the road cost required to support added tractor skidding areas. For example, going from alternative D to F switches 38 net acres from cable logging to tractor logging, and increases road costs from $48,261 to $71,124.

Also, alternative C specified one road on the southeast-facing midslope built to the minimum standard required to satisfy soil protection guidelines. Note that the total cost difference between alternatives A and C is only $0.97 per net thousand bd ft. If road costs for alternative C could be reduced from $30,816 to $28, 245, the cost per net thousand bd ft would be equal for alternatives A and C.

Table 2. Alternative costs for initial entry

Alternative[1]	Cable yarding area	Gross volume[2]		Total cost					Cost per net M bd ft[3]				
		Cable yarding	Tractor skidding	Cable yarding	Tractor skidding	Skidding and yarding	Road	Total	Cable yarding	Tractor skidding	Skidding and yarding	Road	Total
	Acres	*M bd ft*		*Dollars*					*Dollars*				
A	125	659.160	2870.940	36,455	15,675	52,130	17,095	69,225	73.74	7.28	19.69	6.46	26.15
B	115	610.103	2919.997	32,887	16,031	48,918	30,816	79,734	71.87	7.32	18.48	11.64	30.12
C	115	610.103	2919.997	24,958	16,031	40,989	30,816	71,805	54.54	7.32	15.48	11.64	27.12
D	88	373.450	3156.649	18,506	17,875	36,381	48,261	84,642	66.07	7.55	13.74	18.23	31.97
E	59	420.716	3109.384	16,352	17,350	33,702	53,679	87,381	51.82	7.44	12.73	20.27	33.00
F	50	238.827	3291.272	10,873	18,834	29,707	71,124	100,831	60.70	7.63	11.22	26.86	38.08

[1]*Alternatives A and B assume a yarder with a capital investment of $170,000. The remaining alternatives assume a yarder with a capital investment of $100,000.*
[2]*Computed from data in R-3 Thomas Creek sale analysis printout.*
[3]*Computed using 25% combined woods and mill defect.*

Cable Yarding Costs

Yarding on the South Thomas Creek watershed will require a yarder with a reach of either 1,500 ft or 900 ft, depending on which access road alternative is chosen. Specifications were reviewed for several yarders in both size classes. One typical 1,500-ft-reach yarder used in a live skyline configuration cost approximately $170,000 in late 1975. A typical 900-ft-reach yarder also used in a live skyline configuration cost about $100,000 in late 1975. In the following discussion these are termed "intermediate yarder" and "small yarder", respectively.

Load carrying capability for each yarder was determined by use of a load path analysis computer program,[7] with the following specifications assumed for each yarder.

	Intermediate yarder	Small yarder
Skyline diameter, in	1.00	0.75
Skyline length on drum, ft	1,930	1,100
Mainline diameter, in	0.75	0.56
Mainline length on drum, ft	1,870	1,800
Tower height, ft	48	42
Tailspar height, ft	30	30
Carriage weight, lbs	500	500

This analysis estimates payload weight that can be carried on each turn, a figure important in the appraisal process to estimate bd ft volume of logs carried per turn.

[7]*U.S. Dep. Agric., For. Serv., Rocky Mt. Reg. Unpublished documentation for computer program, SKYSL. n.d. This program is based on work done by Ward Carson and others at the Pacific Northwest Forest and Range Exp. Stn.*

Yarding distances are longest on both sides of the lower end of the watershed. While the skyline may be anchored at a point considerably more than 1,000 ft from the yarder on these few settings, the carriage will seldom, if ever, be more than 1,000 ft from the yarder. A 3/4-in mainline should not be too heavy for manual slackpulling; however, if a lighter 9/16-in mainline were required, payload will necessarily be smaller on any given setting.

Current Forest Service timber appraisal methods estimate cable yarding costs on both a total and a per-thousand-bd-ft basis (USDA Forest Service 1975). Required input data include number of logs per thousand bd ft, number of logs per acre, average rigging time per setting, and the machine rate of the yarder in dollars per hour. The appraisal procedure estimates production per hour, total time required for all settings, cost of yarding, cost of constructing landings, and cost of crew transport. Total costs are shown in table 2.

Tractor Skidding Costs

The Appraisal Handbook for the Southwestern Region provides data for estimating costs of tractor skidding (USDA Forest Service 1972). Total tractor skidding area is stratified into subareas based on uphill or downhill skidding, percent sideslope, average log volume, and average skid distance. The appropriate appraisal tables are entered with these average figures for each subarea, and cost factors are extracted to modify the regional average cost figures. Finally, an overall average cost per thousand bd ft for the whole skidding area is found by weighting cost for each subarea according to its log volume.

Costs derived by this method are shown in table 2. Tractor skidding volume increases from alternative A to F, except for alternative E. For alternative E, skid volume decreases, lowering total skidding cost proportionately. For tractor skidding only, alternatives B and C are identical.

Total Costs

To compute total costs for the entire watershed, cable yarding and tractor skidding costs were weighted by volume cable-yarded or tractor-skidded. Cruise data suggested that a 25% defect factor was average for trees on the harvest site. Therefore, costs per thousand bd ft gross scale for roads, cable yarding, and tractor skidding were totalled and converted to a net scale basis, using the 25% defect factor (table 2).

Alternatives A and B use a mobile intermediate yarder for settings with skyline spans to 1,500 ft. This yarder would require access roads either on both ridges (alternative A), or on one ridge and a midslope (alternative B). Low road costs for alternative A more than offset the higher capital and operating costs of this yarder, which results in the least cost yarding system for this analysis (table 2).

The last four alternatives employ a smaller yarder for settings with skyline spans to 900 ft. Alternative C has the same road system as alternative B but uses the smaller yarder, the only instance where this happens. By judicious use and location of tailspars, the smaller yarder can just barely satisfy yarding distance requirements with the road locations of alternatives B and C. Economically, alternative C is the opposite of alternative A, because in alternative C higher road costs are offset by lower capital and operating costs of the smaller yarder.

Discounted Alternative Costs[8]

A 120-year rotation with a stand treatment at 20-year intervals requires seven entries, including the initial one. An analysis using current values of future costs suggests which strategy is least expensive from an economic viewpoint — to build higher cost midslope roads and spend less for a smaller yarder at each entry, or to build lower cost roads on the ridges and spend more for a larger yarder at each entry. In this analysis it was assumed that road costs are a capital investment extending over the entire rotation period and that logging costs would be equal for each entry. Road costs for each entry after the first were assumed to be for road grading only, regardless of original road standard, and for subsequent closure.

Some environmental aspects, such as prevention of sedimentation, are built into significantly higher road costs for increasing sideslopes. This analysis is primarily economic, however, so other environmental features, such as esthetics, which in many cases would have importance equal to or greater than the treatment cost, are not quantified.

Discounted costs for all alternatives are shown in table 3, but only alternatives A and C are discussed further because they have the two lowest discounted costs.

At a 6% discount rate, alternative C costs less than A over a 120-year rotation. However, a high-

[8] *John Sessions, USDA Forest Service Logging Systems Training Program, Corvallis, Oregon suggested the analysis of discounted alternative costs.*

Table 3. Estimated cash flow for one rotation discounted to present value at three interest rates[1]

Alternative (1)	Cable yarding cost: Each entry[2] (2)	Cable yarding cost: Present value of total rotation entry, 6% (3)	Tractor skidding cost: Each entry[2] (4)	Tractor skidding cost: Present value, 6% (5)	Road cost: Initial cost (6)	Road cost: Each reentry[3] (7)	Road cost: Present value, 6% (8)	Total cost, present value, 6%[4] (9)	Total cost, present value, 10% (10)	Total cost, present value, 14% (11)
					Dollars					
A	36,455	52,957	15,675	22,770	17,095	11,167	5,055	97,877	80,275	74,192
B	32,887	47,773	16,031	23,287	30,816	11,836	5,358	107,234	90,340	84,501
C	24,958	36,255	16,031	23,287	30,816	11,836	5,358	95,716	81,027	75,950
D	18,506	26,883	17,875	25,966	48,261	12,158	5,503	106,613	93,116	88,451
E	16,352	23,754	17,350	25,203	53,679	14,006	6,340	108,976	95,710	91,125
F	10,873	15,795	18,834	27,359	71,124	14,328	6,486	120,764	108,519	104,286

[1]*The factors for this analysis were obtained from Table 2 in Lundgren (1971). The interest rate was applied for 20 years, 40 years, etc. up to one rotation of 120 years.*
[2]*Assume that identical cable yarding and tractor skidding costs will be incurred at each 20-year entry.*
[3]*Includes regrading and closing cost at each 20-year entry.*
[4]*Figures in column 9 are the sum of figures in columns 3, 5, 6, and 8 for each alternative.*

er discount rate is probably more realistic. In table 3, discounted total costs at either a 10% or 14% rate show alternative A costs less than C, in contrast to the result at the 6% rate. In any case, the differences are slight for the two alternatives over the 120-year period.

Since present assumptions about logging technology and associated road requirements are not likely to remain valid for much more than 20 years, the relative ranking of alternatives A and C for a 20-year period should be considered. This interval corresponds to the initial treatment plus one reentry. Figure 2 shows the present value of cost differences between alternatives A and C for a range of discount interest rates and for a 20-, 40-, and 120-year time period.

A curve value in figure 2 is positive when alternative A costs more than C at the end of the time period for a selected interest rate. When a curve value is negative at a given interest rate, alternative A costs less than C at the end of the time period. For example, at an 8% discount rate, alternative A costs $290 more than C for 120 years, but $334 less than C when the time period is limited to 20 years.

Obviously, interest rate and time period assumptions can have a great effect on discounted cost analyses. On the South Thomas Creek watershed, an interest rate choice of about 9% or greater will always result in alternative A costing less than C for any time period less than 120 years.

Summary and Discussion

Opportunities for combined tractor and cable logging will likely increase in the central and southern Rocky Mountains. The purpose of this case study was to bring together and apply current appraisal techniques to determine the combined cost of tractor skidding and cable yarding on a specific site.

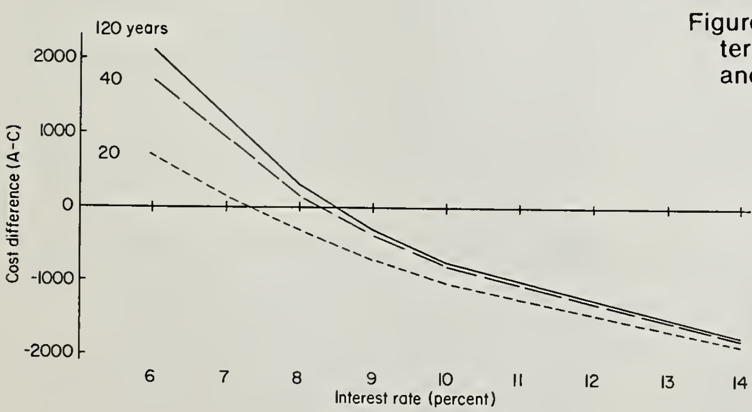

Figure 2.—Discounted cost difference between alternatives A and C for a range of interest rates and time periods.

An analysis was made of the topography on South Thomas Creek to classify areas by percent slope. This information was used to determine the location of suitable roads and to determine which areas of the watershed could be tractor skidded and which areas could be cable yarded only.

Six technically feasible combinations of roads, cable yarding, and tractor skidding were examined. Two combinations, alternatives A and C, cost significantly less. For the initial treatment entry, alternative A costs slightly less than alternative C, while for seven treatment entries during a 120-year rotation, alternative C costs slightly less than alternative A, using a 6% discount interest rate. However, with interest rates of about 9% or greater, alternative A costs less than C for any time period up to 120 years.

This analysis is primarily economic rather than environmental but does reflect increased soil protection costs in terms of road standards. Qualitative effects such as esthetics are not included, and even though economic ranking includes some environmental considerations, it is recognized that other factors defined in Forest Service Environmental Analysis Reports may take precedence when deciding between alternative skidding or yarding plans. Improved technology will likely make the technical assumptions of this analysis obsolete before the end of the 120-year rotation, possibly before the end of the first 20-year interval. Thus, projections of long-term costs are dependable only as long as they continue to represent relative costs between alternatives.

This analysis demonstrates cost tradeoffs between yarding and skidding costs and road costs. Such analysis may be useful in evaluating broader concepts. For example, the idea has recently developed that smaller, less expensive yarders are needed to harvest small timber on steep slopes in the Rocky Mountains. However, it is apparent from this case study that if using smaller yarders always implies a short reach, increased access road costs could offset capital savings on the yarder. This implies that while there may be a place in the central and southern Rocky Mountains for short-reach yarders, there may also be a place for larger yarders with a reach from 1,500 to 3,000 ft, where the reduced cost of low density access roads would offset the higher capital and operating costs of larger yarders.

One possible way to reduce access roads is to combine high flotation tracked skidders with long reach cable systems. For example, a tracked skidder with a low center of gravity and low ground pressure has recently been used in western Canada on slopes up to 50% (Overend 1975). Such a skidder could be used to deck logs from steep slopes at a concentration point remote from the main access road. A long-reach cable yarder could then swing yard the logs to the road with efficiency because few moves of the skyline would be required (Mason 1976). An analysis similar to this could be used to estimate the comparable costs of this alternative.

It is significant that this small (562-acre) watershed had at least six feasible alternative road, skidding, and yarding combinations out of the many that could be considered. Larger harvest areas conceivably might have several times this number of alternative combinations of access roads, tractor skidding and cable yarding areas. The variety of these factors in future timber sales could provide hundreds of possible case analysis situations analogous to the one described here.

Extensive analysis of many combinations of cable yarding, tractor skidding, and road location using manual computation methods would be prohibitively expensive. Using such methods, this manual analysis, covering only six alternatives, required an estimated 25 man-days over a 6-week period. A computerized system for harvest alternatives analysis would allow much more comprehensive presale planning without greatly increasing the planning effort but would require a large initial investment in computer program development.

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