Cable yarding residue after thinning young stands: a break-even simulation

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Abstract

The use of cable logging to extract small pieces of residue wood may result in low rates of production and a high cost per unit of wood produced. However, the logging manager can improve yarding productivity and break even in cable residue removal operations by using the proper planning techniques. In this study, break-even zones for specific young-growth stands were developed with data from a field study, break-even analysis, and a simulation model called THIN. Results suggest that logging contractors can break even by developing and using residue removal guidelines for various combinations of piece sizes and slope yarding distances. Simulation analysis was used to explore the effect on production rates of slope yarding distances, piece size distributions, and numbers of pieces per acre. For the $76-per-hour machine used, the results of break-even analysis were most affected by piece size. Slope distance also had a strong impact. The number of pieces per acre had the least effect on production rates and costs.

The thinning of young, unmanaged stands creates large quantities of wood residue that could be used for energy.[1] Residue consists of tops and limbs, broken logs, old cull logs left behind from previous harvests, and standing and downed hardwoods.

Recently there has been tremendous interest in increasing the use of logging residue for energy and thus providing alternative fuel supplies.[2] The desire to achieve a more efficient use of logging residue must be balanced against logging cost, product values, and landowner cleanup objectives. A rigorous financial evaluation must be performed and the logging analyst must be familiar with the effects of site-specific variables on the cost of a particular logging operation and with the productivity of any proposed residue removal venture.

Handling of small pieces of residue is a problem for the logging manager. The removal of small pieces, coupled with long external yarding distances, generally results in low productivity rates and increased costs, much of which can be attributed to the use of expensive cable systems to extract the residue.

One method for improving productivity is to use external yarding distance as a criterion for the removal of residue and to remove only larger pieces of residue if the yarding distance is long. Matching yarding distances with piece sizes may make residue removal economically feasible. However, decisionmakers must know which variables affect cost and production and understand how those variables interact if they are to determine whether residue removal is economically feasible for a particular harvesting operation; decisionmakers must also be able to determine the total amount and individual size of residue pieces that can be removed without sustaining a loss. In this article the effect on production costs of alternate slope yarding distances and piece size distributions is evaluated with a simulation model called THIN[3]; the results are used to develop economic guidelines for the removal of residue from thinnings.

[1]LeDoux, C.B., and T.C. Adams. 1983. Harvesting residue from thinnings for use as an energy source. Final Rept. to U.S. Dept. of Energy, Interagency Agreement No. DE-AI51-81R000699. 23 pp.

[2]USDA Forest Service. 1981. Harvesting and utilization for forest residues in the northern Rocky Mountains. Symp. proc. Gen. Tech. Rept. INT-110. Ogden, Utah.

[3]LeDoux, C.B., and D.A. Butler. 1981. Simulating cable thinning in young-growth stands. Forest Sci. 27(4):745-757.

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Using THIN to develop productivity rates

For skyline residue yarding, the THIN algorithm simulates the location and hooking of the first piece of residue and then the process of adding pieces to the turn. The simulation continues to add pieces to the turn, provided that the skyline payload capacity has not been exceeded, that adequate chokers exist, and that added pieces are not more than a specified distance from the first hooked piece (Fig. 1). The user can specify alternate external slope yarding distances and residue piece sizes as inputs to the model. The algorithm can then build turns and estimate hourly productivity rates subject to changes in slope yarding distances and in the statistical distribution of residue piece sizes.

The user should carefully choose the value used as the maximum-distance-per-turn in pulling the hooking line from the first residue piece hooked to additional pieces; this value is an input to THIN. It is common practice for the hooking crew to pull line laterally from the carriage, hook one or more pieces of residue, pull line to additional pieces and hook them, yard the turn toward the skyline road, stop, and add pieces to complete the turn. The length of chokers flown can be one measure of the maximum-distance-per-turn allowed for pulling the hooking line in situations in which choker length is increased slightly to account for additional line pulling or effort by the hooking crew when building a turn.

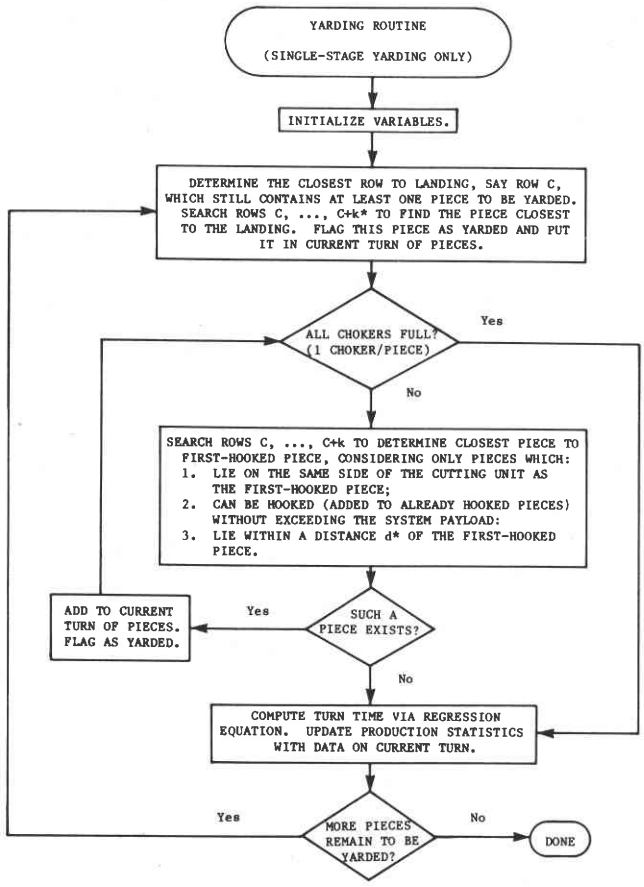

Figure 1. — Flowchart of THIN's simulated yarding routine (LeDoux and Butler, 1981).

The simulations reported in this article employed a value of 43 feet for the maximum distance that hooking line can be pulled from the first hooked log. This distance should not be confused as the maximum lateral distance allowed; it is simply the maximum distance allowed from the first hooked log.[3] This distance was selected after detailed examination of turn distributions from field studies of residue yarding.[4,5] The user can explore the costs and benefits of other distances simply by running additional simulations.

Data from a field test[5] conducted in a young stand were used in this study to illustrate the effect of alternate slope yarding distances and piece size distributions on hourly production rates and costs. The simulation model was then employed to evaluate the effects of each variable on yarding productivity by allowing that variable to change in value while holding the remaining variables constant. The results summarized reflect residue yarding production for a skyline corridor 1,000 feet long and 200 feet wide.

Slope yarding distance

Generally, the farther out on the slope one goes to hook turns of residue, the lower the hourly productivity rate and the higher the cost per unit. Table 1 shows the effects of changes in slope yarding distance on hourly production rates. In all cases, hourly productivity drops significantly as one goes farther out on the slope. For example, if piece size averages 6.0 cubic feet and slope yarding distance is 350 feet, the productivity rate is 273.82 cubic feet per hour. If average piece size remains unchanged, but slope yarding distance increases to 950 feet, productivity drops 31 percent, to 188.32 cubic feet per hour. This drop in productivity obviously reflects an increase in cost per piece, which must be evaluated in light of the silvicultural objectives and of the size-distribution of pieces that can be yarded economically.

Residue piece size and distribution

Generally, increases in the size of pieces removed improve productivity and reduce costs. Removing smaller pieces usually results in low productivity and high costs that make residue removal infeasible. Table 1 shows the hourly production rate for various combinations of average piece size and slope yarding distance. For example, assume that we are yarding residue to distances of 650 feet, that the average piece size is 6.0 cubic feet, and that the hourly production rate is 215.09 cubic feet. If slope distance remains unchanged but average piece size increases to 12 cubic feet, the hourly

[4]LeDoux, C.B. 1984. Production rates and costs of cable yarding wood residue from clearcut units. Forest Prod. J. 34(4):55-60.

[5]_____ and T.C. Adams. 1983. Harvesting residue from thinnings for use as an energy source. Final Rept. to U.S. Dept. of Energy, Interagency Agreement No. DE-AI51-81R000699. 23 pp.

TABLE 1. — *Effect on hourly production rate of changes in average piece size and slope yarding distance.*

Slope distance[a]	Average piece size (ft.^{3})						
	2.0	4.0	6.0	8.0	10.0	12.0	16.0
(ft.)	(production per hour (ft.^{3}))						
50	111.84	234.47	348.01	453.45	551.61	643.00	792.52
150	108.95	220.75	324.98	422.39	513.62	599.25	737.38
250	104.89	212.17	312.48	406.48	494.74	577.78	711.76
350	90.23	184.72	273.82	357.96	437.55	512.94	636.71
450	80.93	169.38	253.10	332.46	407.79	479.39	598.72
550	74.47	156.02	233.55	307.35	377.68	444.78	556.46
650	73.22	145.75	215.09	281.45	345.01	405.95	504.07
750	67.49	140.22	209.76	276.29	340.03	401.13	502.84
850	64.63	134.63	201.66	265.92	327.56	386.75	486.09
950	61.06	125.96	188.32	248.27	305.96	361.50	454.57

[a]Skyline corridor is 1,000 feet long and 200 feet wide.

TABLE 2. — *Effect on hourly production rate of changes in average piece size and number of pieces per acre.*

Pieces per acre[a]	Average piece size (ft.^{3})						
	2.0	4.0	6.0	8.0	10.0	12.0	16.0
	(production per hour (ft.^{3}))						
100	80.67	166.24	247.38	324.43	397.68	467.42	582.41
150	84.24	172.88	256.77	336.28	411.74	483.46	601.10
200	86.52	176.13	260.87	341.14	417.27	489.59	607.52
250	88.31	179.99	266.58	348.50	426.11	499.74	619.78
300	88.95	181.85	269.53	352.41	430.87	505.27	626.77
350	88.26	180.54	267.66	350.04	428.07	502.08	623.03
400	87.78	179.50	266.12	348.07	425.70	499.36	619.72

[a]Skyline corridor is 1,000 feet long and 200 feet wide.

production rate increases by 89 percent, from 215.09 to 405.95 cubic feet (Table 1).

Table 2 shows the effect on hourly production rates of changes in the number of pieces of residue per acre and in average piece size. Generally, the effect of pieces per acre on yarding production is less than the effect of changes in slope yarding distance or average piece size. For example, consider the hourly production rates when average piece size is 6.0 cubic feet and there are 100 pieces per acre and 400 pieces per acre. The hourly production rates are 247.38 and 266.12 cubic feet, respectively, an 8 percent increase. In contrast, yarding larger residue pieces that average 16.0 cubic feet at 100 and 400 pieces per acre results in only a 6 percent increase, from 582.41 to 619.72 cubic feet per hour. Thus, it is clear that average piece size has a greater impact on logging costs than does the number of pieces per acre. The above results can be used to develop guidelines for break-even removal.

Break-even analysis

The break-even analysis assumes a super-marginal move-in and -out operation as well as rig-up and -down. The analysis then focuses only on yarding costs and productivity. The analysis is based on the assumptions that the machine and crew hourly operating cost is $76 and that the residue is sold at the roadside as stacked firewood. To develop break-even guidelines while simultaneously considering the impact on production costs of slope yarding distance and average piece size, the data in Table 1 are rearranged and shown in Figure 2. Generally, hourly productivity drops as slope yarding distance increases and piece size decreases. Residue yarding guidelines that do not consider both factors are likely to produce infeasible economic results. The ideal would be to use slope yarding distance to govern removal of residue of a given size so that market value and extraction costs at least offset each other and thus result in a break-even operation.

Accordingly, consider the estimated cost per unit produced as shown in Figure 2 (far right y-axis). If we assume a roadside market value of $35 per stacked cord, the production cost must equal — that is, it cannot be greater than — this $35 value if the operation is to break even. The line that indicates the $35-per-cord market value and that runs across Figure 2 shows the combinations of average piece size and slope yarding distance possible for a break-even operation. For example, at production costs of $0.27 per cubic foot, a logger could afford to yard 6.0-cubic-foot pieces no farther than 285 feet, and 8.0-cubic-foot pieces no farther than 571 feet. Similar analysis could be conducted for any product price.

The data shown in Figure 2 can be rearranged to show the range of average piece sizes and slope yarding distances that would result in a break-even operation (Fig. 3). In Figure 3, the solid line shows the combinations of slope yarding distance and average piece size that result in a break-even operation within each slope yarding distance shown. The cross-hatched area shows the zone of economic profitability, while the unshaded area below the break-even line shows the area of economic loss, which of course reflects an infeasible operation.

The field manager and logging crew may find analysis of figures such as those developed above difficult to apply in the field; therefore, the next section

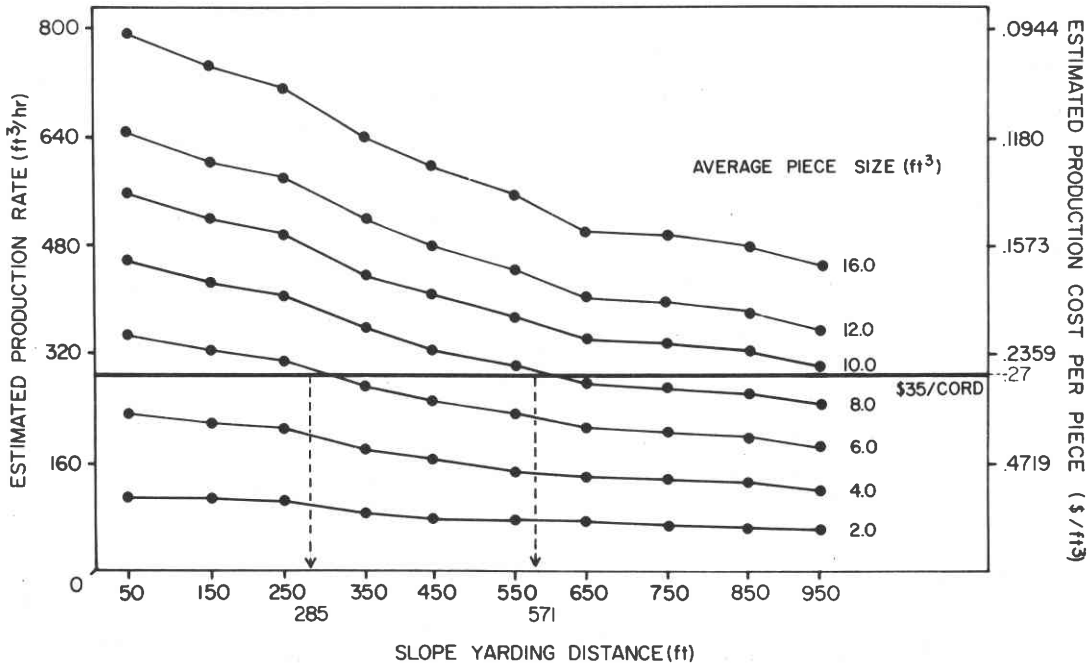

Figure 2. — Simulated production rates and costs of skyline yarding for various combinations of piece size and slope yarding distance. Horizontal line shows size/distance combinations at which operation would break even, assuming residue is sold for $35 per stacked cord and that machine and crew operating cost is $76 per hour.

describes how the data and results can further be rearranged for practical applications.

Practical applications

Assume a logging operation in a typical rectangular skyline corridor whose slope distance is 1,000 feet and lateral distance is 200 feet similar to the conditions simulated. The previous discussion makes it clear that, if the operation is to break even, guidelines must be set on the size of pieces to be removed and the slope yarding distance allowed for removal. The market price at which removed residue can be sold is also a factor in setting these guidelines.

Assume, as in Figure 3, that the market price is $35 per stacked cord. Figure 3 and the previous discussion indicate the appropriate piece size and slope-yarding-distance guidelines for the hooking crew working in the skyline corridor; the crew would be instructed to hook pieces 5.2 cubic feet if the slope yarding distance is 0 to 200 feet, 6.2 cubic feet in the 200- to 600-foot range, and only pieces 9.0 cubic feet from 600 feet on. This policy would result in the operation breaking even. However, hooking pieces larger than those specified by zone to break even would clearly result in profit.

Note that Figure 3 suggests that one should hook, for example, 8.0-cubic-foot pieces at a slope yarding distance of 600 feet; this holds true if slope yarding distance is broken down into the 100-foot-long short hauls shown on the x-axis of Figure 3. However, remember that our practical application assumes that the logger will deal with a slope yarding range of 600 + feet when he is matching piece size to slope yarding distance. Thus the size of the piece to be hooked should

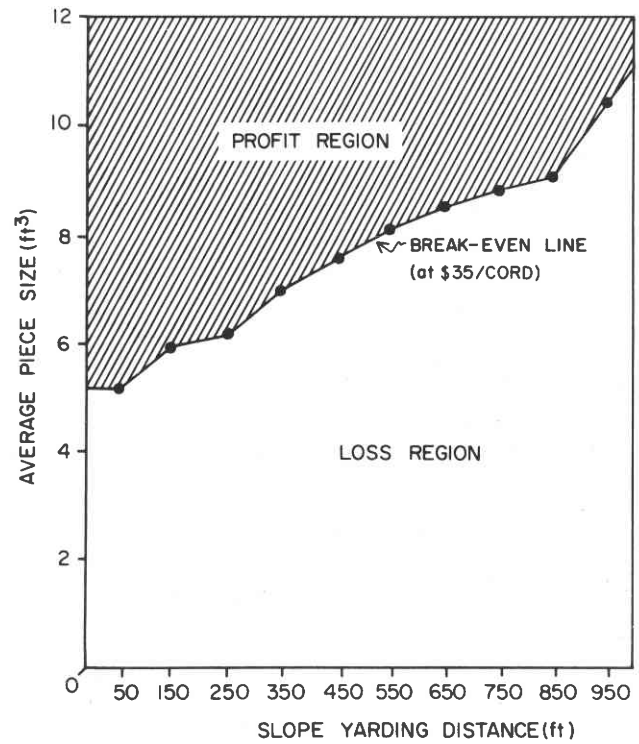

Figure 3. — Simulated economic regions and break-even line for cable yarding of residue that is sold for $35 per stacked cord. Cross-hatched area shows combinations of average piece size and slope yarding distance that are economically feasible and yield a profit within each slope yarding distance shown; line shows size/distance combinations that allow break-even operation, and unshaded area (below line) shows size/distance combinations that yield loss. Skyline corridor is 1,000 feet long and 200 feet wide.

allow for break-even operation throughout the entire 600+-foot-range, rather than selecting incremental sizes that can be hooked profitably within each of the shorter hauls that fall within the longer slope yarding range.

Admittedly, the hooking crew might experience some concern about how crew members would determine rapidly whether a given piece is 5.2 cubic feet, 6.2 cubic feet, or whatever the desired size might be for a given slope yarding range. However, given the desired volume of a piece, one can easily develop a matrix of mid-diameters and lengths that would yield the desired size (Fig. 4). A piece whose mid-diameter and length falls on or below the stairstep line (that is, in the shaded area) would constitute the desired size and should be hooked. Similar matrices could be developed for alternate desired piece sizes. The hooking crew could then easily determine which pieces to take and at what slope distances. Ideally, the break-even analysis would be done prior to the actual logging operation. Clearly the methodology would not work very efficiently if the crew had to develop the break-even contours concurrent with the logging.

Considerations for managers

Regional planners or forest managers may wish to develop break-even residue removal policies on a larger scale for wider application. Accordingly, the data developed above could be arranged to develop contours, such as those shown in Figure 5, of zones for which residue removal operations should break even. Such contours could be used by loggers, silviculturists, wildlife and fisheries biologists, and others involved in

Volume of piece = 9.0 ft^3

$$\text{Volume} = C \cdot L$$

WHERE:

C = Basal area at piece's center

$= 0.005454154\ D^2$

D = Diameter at piece's center

$= \dfrac{\text{Diameter of piece's large end} + \text{diameter of piece's small end}}{2}$

L = Length of piece (in feet)

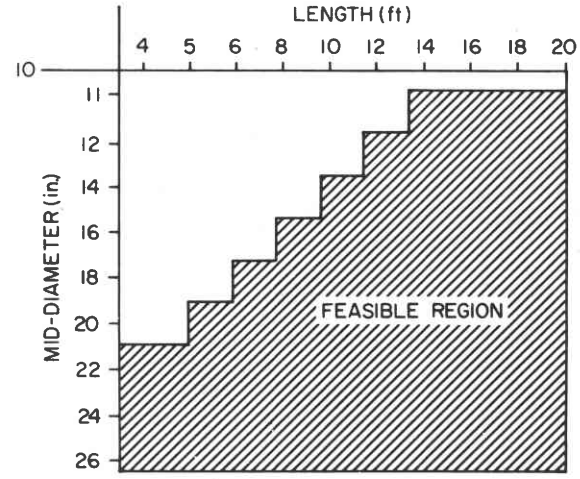

Figure 4. — Matrix of mid-diameters and lengths for residue pieces of at least 9.0 cubic feet. Piece is 9.0 cubic feet or larger if its mid-diameter and length fall on or below the stairstep line.

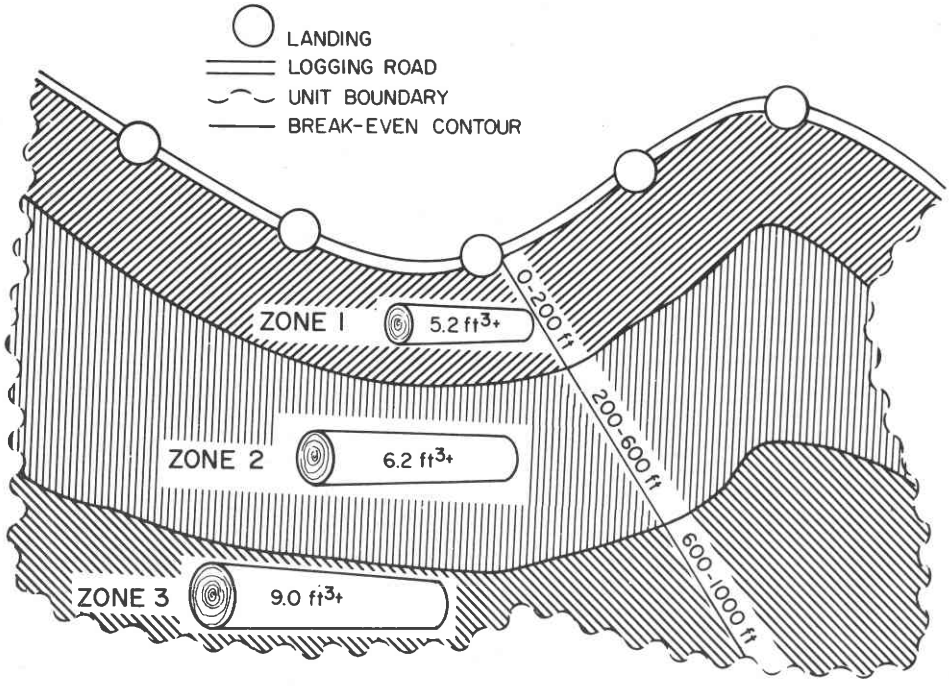

Figure 5. — Simulated contours of break-even residue removal zones for a typical skyline logging unit. Skyline corridor is 200 feet wide. In Zone 1, operator could break even removing residue pieces 5.2 cubic feet; in Zone 2, 6.2 cubic feet; and in Zone 3, 9.0 cubic feet.

forest management who wish to visualize and evaluate the impact of alternate residue removal policies. Clearly, the contours shown in Figure 5 consider only logging costs and market values. Other concerns could easily be integrated into such an approach. Admittedly, the results summarized here reflect a specific set of conditions. However, given other conditions, similar analysis could be conducted. The break-even contours should be developed on a site-by-site or case-by-case situation to be most accurate and effective.

A methodology using field data, simulation, and break-even analysis such as the one presented in this paper will not answer all questions about residue removal. However, this methodology will aid decision-makers in the financial evaluation of ways to remove residue from young stands.