HARVESTING COST MODEL FOR SMALL TREES IN NATURAL STANDS IN THE INTERIOR NORTHWEST

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ABSTRACT

Realistic logging cost models are needed for long-term forest management planning. Data from numerous published studies were combined to estimate the costs of harvesting small trees in natural stands in the Interior Northwest of North America. Six harvesting systems were modeled. Four address gentle terrain: manual log-length, manual whole-tree, mechanized whole-tree, and mechanized cut-to-length systems. Two cable systems were included for steeper terrain: manual log-length and mechanized cut-to-length systems. A stand-alone program incorporating all the relationships is available.

Under ecosystem management, the objectives of forest managers have changed. Maintenance or enhancement of old-growth characteristics and structural diversity are encouraged in order to, among other reasons, retain or improve habitat for certain wildlife species. Other objectives include reduction of fuel loading and competition to improve stand health, and minimization of soil disturbance to avoid sedimentation in fish-bearing streams.

Harvesting remains a tool for achieving these objectives, but the emphasis is on thinning and selective cutting of smaller trees rather than traditional clearcutting and/or removal of larger trees. Harvesting costs make up a large percentage of the total life cycle cost of managing a stand, and the relationship between logging costs and stand parameters has a large impact on which silvicultural regimes are feasible. Forest managers in the Interior Northwest need good cost estimates for the newer prescriptions for smaller trees. Relationships are needed to predict costs for reasonable systems that would be used at each entry, i.e., across a wide range of tree size and removals per acre.

Researchers, notably those at the Forest Engineering Research Institute of Canada, Oregon State University, University of Idaho, and the U.S. Forest Service Intermountain and Rocky Mountain Research Stations, have conducted studies on harvesting smaller trees under interior conditions.

OBJECTIVE

Our objective was to combine the information from previous studies into a model that would estimate costs for typical harvesting systems, and realistically reflect the effects on costs of 1) tree volume; 2) removal trees per acre; 3) harvesting unit size, and other variables such as yarding distance and slope.

PREVIOUS MODELS

Many forest harvesting simulation models have been developed, covering the range from single function (e.g., felling or skidding) to complete tree-to-mill operations. Some models simulate the logging process in great detail (19). This is necessary when comparing different equipment combinations for a specific site, but the complexities of these models may make them impractical to use in long-term planning. Some models consider only single activities such as cable yarding (42), and others are applicable to regions other than the West Coast (e.g., 10,22,24).

Models have been developed for West Coast conditions. One dealt only with cable thinning of small trees (39). Another simulated mechanized harvesting of small trees, but required very detailed input and provided extensive statistical output (53). Another was intended to help choose the optimum equipment mix for a specific situation (54). It requires 14 input variables that describe site, stand, and product characteristics.

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Two West Coast models had objectives similar to ours: to provide costs over a wide range of conditions, for general planning. One used regression analysis of simulation results to produce simple cost relations for each stump-to-mill activity for cable logging of Douglas-fir (9,40). A second model was developed for ponderosa pine plantations (8,21).

Approach

We reviewed harvesting studies that had been conducted in the Interior West over the past 30 years, and considered others that we felt were relevant. We divided the studies into two groups: 1) those used to develop the model; and 2) those used to validate it.

Model development

If a study reported harvesting productivity relationships, we tested them to see if the results were logical, and if so, incorporated them in the model. Other studies did not report relationships, but gave a number of useful data points. We developed regression relationships from these and included them in the model. We also incorporated logical relationships where empirical results did not reflect the effects of variables such as stand density. For example, travel distances between stops for cut-to-length (CTL) harvesters were calculated from stand density, assumed trail spacing, and boom reach.

We found several useful studies for many of the harvesting activities. Rather than selecting just one or two, we decided to include all. Each study covered some portion of the range of conditions considered by the model. To prevent excessive extrapolation beyond the range of data for a given study, we applied a relevance weighting function to the estimated cost per unit volume. The function varies from 1.0 (where the study is considered to be highly relevant) to 0 (in portions of the range where the relationships were not likely to be valid). To avoid sharp transitions in costs, we used linear ramps to connect the 0 and 1 plateaus. Over the range of piece size, we generally assigned a value of 1.0 over the whole observed range, and ramped down to 0 at twice the maximum observed piece size. We also used a ramp on the lower end of the range if the study focused primarily on larger material.

A production rate in cubic feet per productive machine hour (PMH) was calculated from the relationships for each pertinent study for a given activity, e.g., felling and bunching. Costs ($/PMH) were calculated via the traditional before-tax, machine cost approach (4,49), using November 1998 equipment purchase prices. The hourly costs were divided by the production rates to give costs per 100 cubic feet (CCF) for each pertinent study. These were multiplied by their respective relevance weights, summed, and divided by the sum of the weights to give the weighted average cost for the activity.

We implemented the model as a Microsoft Excel workbook. It was then packaged, along with a Visual Basic interface, as a stand-alone program (7). Users can change values such as hourly costs.

Model verification

A second group of studies – those that reported only a small number of point estimates of harvesting production – was used to validate the model. We focused on individual activities, e.g., forwarding, as this is how most studies reported their results. Productivity rather than cost was used, to eliminate differences in costing assumptions.

Our null hypothesis was that modeled results were not significantly different on average from those in the real world as represented by the point estimates. Each of these studies reported some or all of the variables that are inputs to the model: tree volume, removal density, yarding distance, etc. The model was run with these values to produce a result that could be compared with the reported point estimate.

We made two statistical analyses for each harvesting activity. A paired t-test was used to determine if the mean difference between the reported and modeled results was significantly greater than zero. If so, the null hypothesis would be rejected and this would indicate that the model might not be accurate.

Since each harvesting function is strongly dependent on at least one variable (e.g., tree volume), we ran a second, more discriminating test: a regression analysis that included indicator variables to separate the reported and modeled observations. The resulting equations were of the form:

$$\text{Productivity} = a + b \times (\text{primary variable}) + \text{ModeledDummy} \times [c + d \times (\text{primary variable})]$$

If the c or d coefficients were significant, the regressions for the reported and modeled results would be significantly different and the null hypothesis would be rejected.

Elements of the model

Harvesting systems

Ground-based (tractive) systems

A. Manual log-length: 1) chain saw fell, limb, and buck; 2) skid unbunched logs; 3) load; and/or 4) chip. Trees are felled, limbed, and bucked into logs at the stump. Rubber-tired skidders (both choker- and grapple-equipped models are considered) collect the logs and transport them to the landing. Logs to be transported as such are loaded onto log trucks, while logs to be chipped for board products or fuel are processed through a disk chipper and blown into chip vans.

B. Manual whole-tree: 1) chain saw fell; 2) skid unbunched trees; 3a) process; 3b) load; and/or 4) chip. Trees are felled with chain saws, but not limbed or bucked. Rubber-tired skidders (choker and grapple) collect and transport the whole trees. Trees are chipped or processed mechanically (both stroke and single-grip processors are considered) and loaded onto trucks.

C. Mechanized whole-tree: 1) fell and bunch; 2) skid bunched trees; 3a) process; 3b) load; and/or 4) chip. Trees are felled and bunched; drive-to-tree machines are assumed for flat ground, while swing-boom and self-leveling versions are included for steeper terrain. Rubber-tired grapple skidders transport the bunches to the landing. Processing, loading, and chipping are the same as for the manual whole-tree system.

D. CTL: 1) harvest; 2) forward; 3) load; and/or 4) chip. Mechanized single-grip harvesters fell, limb, and buck the trees at the stump and pile the logs at trailside. Forwarders transport the logs to the landing. Loading and chipping are the same as for the manual log-length system, except the logs are shorter.

Yarding systems

A. Manual log-length: 1) chain saw fell, limb, and buck; 2) yard unbunched logs; 3) load; and/or 4) chip. Trees are felled, limbed, and bucked at the stump. Cable yarders transport the logs to the landing. The types of yarders include Idaho jammers, live skylines, and running skylines. Loading and chipping are the same as for the ground-based manual log-length system.

B. CTL: 1) harvest; 2) yard; 3) load; and/or 4) chip. Mechanized single-grip harvesters fell, limb, and buck the trees, and bunch the logs along predesignated yarding corridors and along harvester trails between the corridors. A cable yarder (a standing skyline with motorized slackpulling carriage was the only machine for which data were available) transports the bunched logs to the landing. Loading and chipping are the same as for the ground-based CTL system.

System limitations

The three systems that include feller-bunchers or harvesters are limited to trees averaging 80 ft.^{3} or less, based on physical limits of some equipment and the ranges of conditions observed in empirical studies. The others are applicable to trees averaging up to 150 ft.^{3} Use beyond that point would involve severe extrapolation.

Slope limits: ground-based manual log-length, manual whole-tree, and mechanized whole-tree are limited to 40 percent or less due to soil disturbance caused by skidding, while the ground-based CTL is limited to 30 percent slope due to forwarder stability limits. There is no limit for the yarding manual system; yarding CTL is limited to 40 percent due to harvester prime mover limitations.

Yarding systems are restricted to maximum (not average) yarding distances of 2,000 feet or less due to line capacities of winch drums.

Harvesting activities

For each activity, the sources or derivation of the associated relations are summarized as follows. All variables are defined in **Table 1**.

TABLE 1. — Variable definitions.

Variable	Units	Definition
ButtDiameter	in.	Tree butt diameter
Chipper hp	hp	Chipper horsepower
$C_{Removals}$		Time adjustment factor due to trees per acre removed, for feller-bunchers and harvesters
C_{Slope}		Time adjustment factor due to slope, for feller-bunchers and harvesters
DBH	in.	Tree diameter at breast height
GT/PMH	ton/hr.	Green tons per productive machine hour
LogVol	ft.^{3}	Volume per log
NonSelfLevelCabDummy		0 = self level cab; 1 = regular; for swing-boom feller-bunchers
ModeledDummy		0 = reported; 1 = modeled
Removals	trees/acre	Trees per acre removed
Slope	%	Fall line slope
Time/Load	min.	Total productive loading time per truck
Time/tree	min.	Time per tree
TreeVol	ft.^{3}	Volume per tree
Vol/PMH	ft.^{3}	Volume per productive machine hour

Chain saw felling

McNeel (43) developed relationships for clearcutting and partial cutting. For some conditions, the predicted time per tree for clearcutting exceeded that for selective felling. This was unrealistic, so we constrained clearcutting time to no more than that for partial cutting. Peterson (50) studied clearcutting of second-growth timber. We fit a relationship to his tabular data for felling time per tree. The terms in this and the following relationships were all highly significant ($p < 0.01$) unless noted:

$$Time/tree = 0.1 + 0.0111 \times DBH^{1.496}$$
$$n = 7, \quad r^2 = 0.998, \quad F = 2147$$

The numbers of data points used to develop this and the following relationships are small because they represent reported averages from the cited studies rather than original data sets.

Chain-saw felling, limbing, and bucking

Kellogg et al. (37) studied chain saw felling and processing in a thinning of a mixed-species, naturally regenerated stand in western Oregon. To adjust for interior conditions, we increased the time per tree by 20 percent for thinning and 10 percent for clearcutting. These and all later adjustments were educated guesses, based on our experience.

Felling and bunching

A. Drive-to-tree: These machines are limited to relatively flat ground, so we assigned relevance weights of 1.0 up to 10 percent slope, dropping to 0 at 20 percent. Johnson (31) studied a skid-steer Melroe Bobcat in thinnings in northern Idaho. Because tricycle prime movers are more popular today, we also included Greene and McNeel's (20) results from Georgia and South Carolina.

B. Swing-boom: Johnson (31) studied a Drott, thinning in northern Idaho, a Caterpillar 227 and a Timbco 2520 with self-leveling cab (32). Gingras (15) reported on a John Deere 693B and a Timberjack 2518 self-leveling machine in clearcuts in Quebec. We fit the following relationship to data (18) for a self-leveling Timbco, working with lodgepole pine in Montana:

$$Time/tree = 0.324 + 0.00138 \times \mathrm{DBH}^2$$
$$n = 27, \quad r^2 = 0.55$$

Weights for the self-leveling machines were set at 1.0 down to 35 percent slope, dropping to 0 at 15 percent because these machines are not likely to be used where the average slope is low. The other swing-booms were considered fully relevant up to 20 percent, dropping to 0 at 30 percent.

For those feller-buncher (and harvester) studies that did not explicitly include slope or removal density in their results, we adjusted times with factors developed from Mellgren's (45) data:

$$C_{Slope} = 0.00013 \times Slope^2 + 0.004 \times NonSelfLevelCabDummy \times Slope$$
$$n = 8, \quad r^2 = 0.977, \quad F = 129$$

$$C_{Removals} = \mathrm{Max}(0, 0.66 - 0.00119 \times 2.47 \times Removals + 5.357\mathrm{E} - 7 \times (2.47 \times Removals)^2)$$
$$n = 5, \quad r^2 = 0.996, \quad F = 223$$

The baseline time per tree is multiplied by: $\{1 + C_{Slope} + C_{Removals}\}$.

Harvesting

Schroder and Johnson (58) studied three small harvesters performing thinnings in Idaho and Montana. Two were on excavator bases (Hitachi EX150 with

Keto 500 head, Komatsu PC95 with Hahn HSG140 head) and one was on a self-leveling prime mover (Timbco T425 with Pika 600 head). Drews et al. (6) observed a Hitachi 200LC tracked carrier with a Keto 500 head. Kellogg and Bettinger (35) reported on a Timberjack 2518 thinning in western Oregon. McNeel and Rutherford (44) observed a Rottne selectively harvesting in interior British Columbia. The processing time relationship was too sensitive to tree length, so we replaced this one element with that from Drews et al. (6). Brinker and Tufts (3) developed relationships for a Norcar 600H in pine plantations in the southeastern United States. Results were given a maximum relevance of 0.5 because of the location of the study; we also limited the production rate to at least 100 ft.^{3}/PMH. Since all of these studies were of partial cutting, the weighted average cost was adjusted downward by 10 percent for clearcutting.

Skidding

Turn volume was estimated as a function of tree volume, type of cut (partial or clearcut), and slope, using relationships reported by Hartsough et al. (21).

A. Choker skidders, unbunched trees/logs: Because of limits on number of chokers, turns were limited to a maximum of 10 logs. Johnson and Lee (34) studied an International S8 skidding residues after a clearcut in Idaho. Gibson and Egging (14) reported on skidders in the interior area. Schillings (57) developed two relationships for skidders in Montana, one for smaller machines (down to 55 hp), and another for larger machines (up to 117 hp). Since the two separate relationships gave counterintuitive relative results in some cases, we averaged them to produce a more realistic relationship. Gardner (11) reported on rubber-tired skidders operating in the northern Rockies.

B. Grapple skidders, unbunched trees/logs: Johnson (32) studied a Caterpillar 518 transporting manually felled whole trees in the Intermountain West. Gebhardt (13) observed rubber-tired skidders in eastern Oregon and Washington.

C. Grapple skidders, bunched trees: Johnson (32) studied a John Deere 648D in the Intermountain West. (We deleted an unreasonable exponential slope term from the travel-empty relationship.) This study covered a limited range of tree sizes and the relationships were limited to a few variables. We supplemented it with a more comprehensive study (59), but we assigned a weight of 0.5 because it was conducted in the Southeast; turn times were also adjusted upwards by 30 percent to reflect Interior Northwest conditions. We limited grapple time to a maximum of 5 minutes per turn, and ungrapple to a minimum of 0.

Forwarding

Schroder and Johnson (58) studied an 8-ton Timberjack 230A, thinning in northwestern Montana. Kellogg and Bettinger (35) reported on a 9-ton FMG 910, thinning in western Oregon; we limited the production rate to at least 100 ft.^{3}/PMH. McNeel and Rutherford (44) observed a 10-ton Rottne in interior British Columbia, and Drews et al. (6) observed a 12-ton Valmet 646 in eastern Oregon.

Cable yarding

A. Clearcut, unbunched logs: Schillings (57) studied an Idaho jammer in Montana. Hensel and Johnson (25) presented results for an Idaho jammer, a Link Belt 98 live skyline, and a Skagit GT3 running skyline. The slope terms in the time per turn relationships for the jammer and running skyline gave unrealistic results for gentle slopes, so we limited the magnitudes of these terms. Gardner (12) developed relationships for a Skagit GT3 running skyline and a Linkbelt 78 shotgun live skyline in western Montana. The shotgun system requires adequate chordslope to return the carriage, so it was considered fully relevant down to 40 percent slope, dropping to 0 at 30 percent.

B. Partial cut, unbunched logs: Johnson and Lee (34) studied a two-drum Clearwater Yarder, removing residues from a clearcut in Idaho. Since lateral yarding was employed and the residue density was much lower than the volume removed in a clearcut, the study was considered to be applicable for partial cutting of small trees. Kellogg et al. (37) observed a Madill 071 live skyline with slackpulling carriage in a thinning. Gardner (12) studied a Skagit GT3 running skyline in shelterwood and group selection prescriptions and a Linkbelt 78 shotgun in group selection, in western Montana. We limited the shotgun as noted previously.

C. Bunched CTL logs: Drews et al. (6) studied a Diamond 210 standing skyline with motorized carriage in eastern Oregon.

Assumptions for cable yarding included a 35-foot average lateral yarding distance (for partial cuts), and an 800-ft.^{2} area to accumulate a turn. Area-limited turn volume is calculated from the area and removal volume per acre. Yarder capacity (for skyline machines) is based on 8 percent deflection, a partially suspended load, and skyline diameter ranging from 5/8 inch for small trees to 3/4 inch for big trees. This gives payload capacities that range from 6,000 to 9,000 pounds.

Corridor change, line shift, and landing shift costs are based on assumptions for area per change or shift, and time per change or shift for each type of yarder. The change or shift cost in \$/CCF is calculated using these assumptions, the hourly cost for the machine, and the volume removed per acre.

Weighted average costs were calculated for all the clearcut and all the partial-cut studies. In some cases, the partial-cut cost was lower than that for clearcutting. To correct this illogical result, the two were averaged, 95 percent of this cost was used for clearcutting, and 105 percent of it for partial cutting. Yarding cost for unbunched logs was constrained to be at least 20 percent greater than skidding cost for unbunched logs under the same conditions. The cost for yarding bunched CTL logs was constrained to be at least 20 percent higher than forwarding cost.

Processing

Johnson (32) studied Roger-Denis and Harricana stroke (slide-boom) processors in the Intermountain West. Schroder and Johnson (58) studied a Hitachi EX150 with Keto 500 single-grip head in northern Idaho. We developed the following relationship from the data Gonsior and Mandzak (18) reported for a Hahn stroke processor, working with lodgepole pine in Montana:

$$Time/tree = 0.141 + 0.0298 \times DBH$$
$$n = 11, \quad r^2 = 0.94, \quad F = 133$$

Peterson (51) presented data for a Lim-mit stroke processor in northern British Columbia. We fit the following relationship to his data:

$$Time/tree = 0.0143 + 0.153 \times ButtDiam$$
$$n = 5, \quad r^2 = 0.97, \quad F = 85$$

Loading

A. Full-length logs: We fit the following relationship to a tabular summary of loading that Jackson et al. (30) provided from a number of studies in the northern Rocky Mountains:

$$Vol/PMH = 11.04 + 0.522 \times LogVol - 0.00173 \times LogVol^2$$
$$n = 14, \quad r^2 = 0.97, \quad F = 197$$

Vaughan (60) developed a loading-time relationship for three front-end loaders (Caterpillar 936, Dresser 520, and Volvo 1610) in New Zealand. Hartsough et al. (21) developed a relationship from loading data reported for studies in California and the southern United States.

B. CTL logs: Brown and Kellogg (5) provided limited data for loading of CTL logs in a study in eastern Oregon. We fit the following relationship to their data:

$$Time/Load = \text{Max}(15, -27 + 190/LogVol^{0.5})$$
$$n = 3, \quad r^2 = 0.98, \quad F = 40.4$$

We also used the relationship that we developed from Jackson et al. (30), to extend the range beyond that covered by Brown and Kellogg (5). Since Jackson's study did not specifically cover short CTL logs, we assigned the relationship a weight of 0.5.

Chipping

A. Whole trees: Johnson (33) presented information on chipping production as a function of chipper power. He also tabulated chipping diameter capacity vs. horsepower. We developed two relationships (power vs. tree size, and production rate vs. power) and combined them to estimate production:

$$Chipper\ hp = \text{Min}(700, \text{Max}(200, 100 + 100 \times TreeVol^{0.5}))$$

$$GT/PMH = -17 + Chipper\ hp/6$$

We developed a relationship from data on a Morbark 22 chipping pine in Oklahoma:

$$Vol/PMH,\ \text{ft.}^3 = \text{Min}(4000, 463 \times TreeVol^{0.668})$$

B. CTL logs: Drews et al. (6) studied a Morbark 27 chipping CTL logs from cold decks in eastern Oregon. We constrained the time to a minimum of 20 minutes per load.

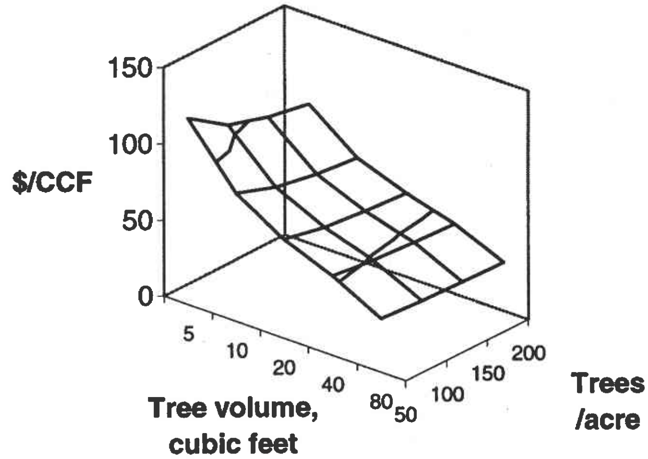

Figure 1. — Example of stump-to-truck cost results. Ground-based CTL system, partial cut, 500-foot average forwarding distance, 20 percent slope, 100-acre unit, 50-mile move-in distance.

TABLE 2. — Validation data sources and results.

Activity	Data sources	Reported obs.	p-value for t-test	p-value for regr. coef. c	p-value for regr. coef. d
Felling and bunching	(2, 23, 26, 29, 41, 55)	20	0.98	0.18	0.12
Harvesting	(1, 5, 16)	12	0.86	0.37	0.51
Skidding	(2, 26, 52)	12	0.07	0.02	0.07
Forwarding	(1, 27, 38, 46, 56)	8	0.17	0.26	0.27
Yarding	(17, 28, 38, 47, 48)	7	0.10	0.72	0.76
Processing	(2, 36, 52)	8	0.10	0.06	0.32

Volume relationships

Many studies indicated tree or log size with cubic volume. For the studies that used other units such as diameter at breast height (DBH), we converted between units with relations developed from an Interior West harvesting study (6). We assumed a constant ratio of 5 board feet per cubic foot, and that butt diameter was 3 inches greater than DBH, for the few cases where these conversions were needed. We assumed a preferred log length of 16 feet for CTL systems, and 32 feet for other systems.

Hourly costs

A single cost was used for a chain saw and operator. Three feller-bunchers (for flat, intermediate, and steep slopes) were considered. For all other activities, costs were calculated for a machine that would be appropriate for the smallest trees considered in the model and another for the largest trees. Interpolation was used to calculate a cost between these two extremes, based on the average tree size.

Move-in costs

Move-in costs, for transport and for the idle equipment, may dramatically affect the overall costs when harvesting small volumes of timber. We calculated move-in costs from two variables, area of the harvesting unit and move-in distance, and assumed fixed travel speeds, labor and truck costs, and loading times.

System cost summary

Cost results were calculated for each activity included in a system, and then summed to get the total stump-to-truck cost per CCF for each system. Since processing, loading, and chipping apply to only a portion of the total volume, the costs per CCF of material flowing through those activities were multiplied by the respective fractions of total volume. Example cost results are shown in **Figure 1**.

Model validation

Sufficient studies with point estimates were available to run tests for felling and bunching, harvesting, skidding, forwarding, cable yarding, and processing. There were inadequate data to test chain

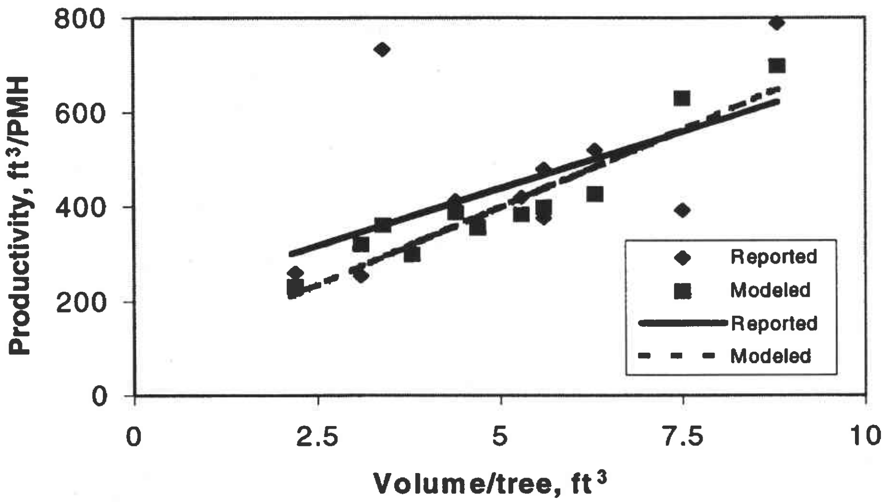

Figure 2. — Validation data and regression lines for harvesting.

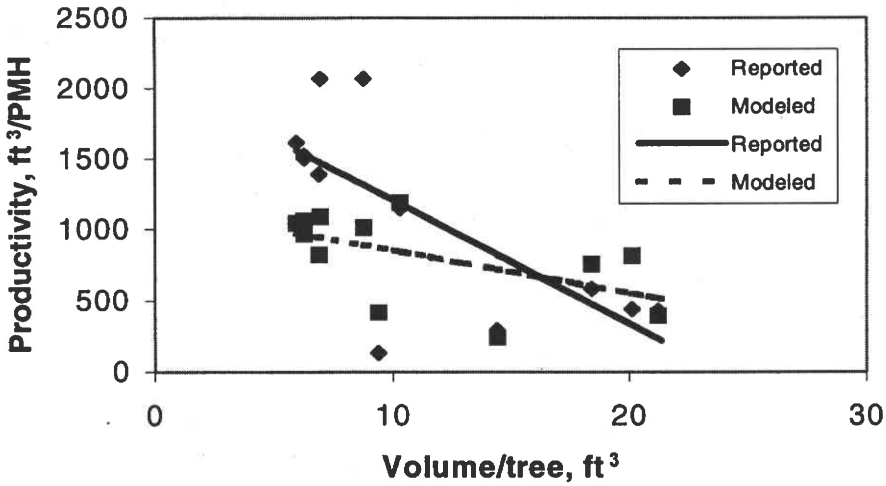

Figure 3. — Validation data and regression lines for skidding.

saw felling, loading, and chipping. The data sources and the validation results are listed in **Table 2**.

The t-tests showed no significant differences ($\alpha = 0.05$) between the means of the reported values and the means of the modeled values for the same conditions. The regression coefficients indicated the same results, except for skidding where the c coefficient was significant. To provide further insight into the validation tests, the best and worst cases (based on the averages of the three p-values for each activity) are detailed in the following paragraphs.

The reported and modeled results for harvesting were closest to each other, with a mean difference of 34 $ft.^3$/PMH, or about 8 percent of the average reported value of 442 $ft.^3$/PMH. The harvesting data and validation regression lines are shown in **Figure 2**. The modeled productivities were close to the reported values in 10 of the 12 cases. In the other two cases with large differences, the reported values appear to be rather anomalous. There may be experimental errors in reported results; there are no perfect standards for evaluating a harvesting model. Overall, the data suggest that the model for harvesters is valid.

Skidding had the least correspondence, with a mean difference between reported and modeled values of 282 $ft.^3$/PMH (26% of the average reported value of 1,100 $ft.^3$/PMH). The data and regression lines are shown in **Figure 3**. (The lower production for the larger trees is due to the studies included in the sample; those for large trees were of choker skidding, whereas the small-tree studies were of grapple skidding of bunched trees.) Obviously, the correspondence between the reported and modeled results for skidding is weak, and this could be viewed as rejecting the validity of the skidding model. But the data set included only 12 observations, small from a statistical perspective. More data is needed to prove or disprove the model.

Limitations of the Model

The relations should not be extrapolated beyond the stated ranges. For example, machines such as feller-bunchers and harvesters all have upper bounds on the size of trees they are capable of handling; limits on these are included in the program. There are physical or administrative situations, however, where the cost results may not be realistic. For example, on dissected terrain, a CTL system will have higher costs and may not even be feasible. As with any simulation model, it is up to the user to verify that the modeled conditions are realistic.

The relations we developed are not appropriate if harvesting system selection or absolute cost is the main item of interest, e.g., for appraisals. For system selection, approaches that consider more alternatives should be used (e.g., 54). For appraisals, the analysis must consider product markets, equipment balancing, and other factors.

Summary

A logging cost model was developed for small trees in natural stands by combining data from previous field studies of forest harvesting in the Interior West and similar areas. The model is appropriate for long-term management planning, where the sensitivity of cost to decision variables is more important than the absolute level of cost.

Our approach, extracting data and relations from the literature, had several deficiencies, including gaps in the data and differences in study conditions. An ideal approach might involve controlled harvesting studies across the full ranges of variables, but it would be prohibitively expensive.

To verify the model, we used point-estimate data for felling and bunching, harvesting, skidding, forwarding, cable yarding, and processing. Statistical tests, in most cases, did not indicate any significant differences on average between the modeled and reported results, but the data sets were not large. The model did not always give results that were close to reported values for many individual cases, but it was not intended to do so. Because it combines relationships from numerous studies, the model is inherently designed to produce results that should be good on average for a given situation, which is what is needed for long-range planning.

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