HARVEST COST COLLECTION APPROACHES AND ASSOCIATED EQUATIONS FOR RESTORATION TREATMENTS ON NATIONAL FORESTS

CHARLES E. KEEGAN III*
MICHAEL J. NICCOLUCCI
CARL E. FIEDLER
J. GREG JONES
ROY W. REGEL

ABSTRACT

Forest managers are constantly faced with the need to reliably estimate harvest costs. Because of the inherently variable conditions under which logging occurs, estimating costs inexpensively is challenging. Yet cost estimates for timber harvest are especially important as new treatments aimed at ecosystem restoration are developed. The approach presented here combines elements of several cost-estimation methods to efficiently estimate stump-to-loaded-truck timber harvest costs for a range of ecosystem restoration prescriptions. This approach relies on detailed information from logging managers to build predictive models. Two equations are presented, one for tractor systems and one for skyline systems in Montana. Stump-to-loaded-truck harvest costs are expressed for harvest volumes ranging from 13 to 125 green tons per acre, for timber ranging from 6 to 10.5 inches in average diameter, and skidding/yarding distances ranging from 600 to 1,800 feet. The equations explained more than 60 percent of the variation in costs, with removal volume, average piece size, and average skidding/yarding distance as highly significant explanatory variables. For tractor and skyline systems, estimated harvest costs decrease $1.27 and $1.31 per green ton with each 1-inch increase in average diameter, decrease $0.06 and $0.13 per green ton for each ton increase in volume per acre removed, and increase $0.69 and $1.26 per green ton for each 100-foot increase in skidding/yarding distance, respectively.

The shift in emphasis on national forest lands from harvest operations designed primarily for commercial timber production to those aimed at achieving more diverse objectives has led to operations that are financially challenging (2). Design and implementation of projects require a better understanding of the cost of harvesting timber under the more complex and variable conditions often encountered in these situations. The USDA Forest Service needs the capability to determine whether a project can be "supported" by the value of timber removed, or estimate project costs if appropriated funds will be required for tree removal.

The Forest Service, due to a change in the timber appraisal process, eliminated its formal harvest cost collection process, and as a result has no rigorous method for estimating harvest costs associated with these diverse projects. Because of the changing emphasis in treatment regimes, forest managers are faced with a need to develop cost estimates for implementing new treatments. Resources

The authors are, respectively, Director of Forest Industry Research and Research Professor, Bureau of Business and Economic Research, School of Business, Univ. of Montana (UM), Missoula, MT 59812; Economist, USDA Forest Serv., Inventory and Monitoring Inst., Missoula, MT 59807; Research Associate Professor, School of Forestry, UM; Research Forester, USDA Forest Serv., Rocky Mountain Res. Sta., Missoula, MT 59807; and Professor, School of Business, UM. This paper was partially supported by funding provided by the USDA Forest Serv. Rocky Mountain Res. Sta., Bitterroot Ecosystem Management Res. Project, the Inland Northwest Forest Products Res. Consortium, the USDA/USDI - Joint Fire Sciences Program, and the USDA Forest Serv., Pacific Northwest Res. Sta. The authors would like to thank Daniel P. Wichman who collected most of the data and members of Montana's logging industry who cooperated in this project. This paper was received for publication in March 2001. Reprint number 9286.
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are limited and traditional harvest cost estimation methodologies can be expensive to develop and time-consuming to implement.

COST-ESTIMATION APPROACHES

There are numerous approaches for estimating production costs, such as those associated with timber harvesting. Several involve statistical modeling of cost data obtained from sources ranging from complex time-and-motion studies, to opinions of managers familiar with the operations or processes (4,6).

Methods differ in the source of data used, assumptions, accuracy of the estimated cost function, and cost of data collection. Ideally, a cost analyst should apply more than one approach, with each approach serving as a check on the others. The choice of methods and degree of complexity should be based on a cost-benefit test (3,4). While there are no "generally accepted rules" for determining how simple or how complex the approach, one should "avoid complexity for the sake of complexity and simplicity for the sake of simplicity. Common sense should be the guide (3)."

Horngren et al. (4) describe four common, overlapping approaches to developing cost estimates: industrial engineering method, conference method, account analysis method, and quantitative analysis method. In this context, quantitative analysis means using a formal mathematical process to fit cost functions to past data observations.

The industrial engineering approach estimates cost functions by analyzing the relationship between physical inputs and outputs (4). Time-and-motion studies are the tool of choice for collecting the physical inputs and outputs. Internally or externally derived costs for the various inputs are used to transform the physical measures into costs.

The industrial engineering method can be a very accurate cost-estimation technique, but is generally expensive and time consuming. It is also difficult to trace indirect costs such as overhead using this approach. This method is most appropriate for situations where costs are estimated for activities that can be replicated with fidelity and relatively easily controlled (4).

The conference method estimates cost information by gathering analyses and opinions about costs from people knowledgeable in the field. It pools expert knowledge from different sources. Cost estimates and functions can be developed quickly; however, emphasis on opinions means the accuracy of the estimates depends largely on the knowledge of the people providing the inputs.

The account analysis method relies on a firm's accounting system. In a simple application, an analyst would examine each cost account in the company's records and specify whether it was variable or fixed with respect to the activity under consideration. The analyst frequently uses qualitative, rather than quantitative, factors to make cost classification decisions. Although account analysis is widely used, its accuracy depends on the analyst's knowledge of the operations in question. Supplementing the account analysis method by the conference method improves its credibility (4).

The quantitative analysis method involving the statistical analysis of historical observations (either time-series or cross-sectional) is used to provide data for various types of mathematical models. This method may provide highly accurate, useful, and relatively inexpensive estimates of costs if data are available and they represent the proposed operation for which costs are to be estimated.

METHODS

Timber harvest operations present some special problems in terms of estimating costs. Although logging is and should be viewed as a part of the manufacturing process, it is not carried out in a factory environment. Because logging takes place in an environment that is inherently variable and difficult to control, obtaining sufficient numbers of observations related to key predictive variables (and under comparable conditions) is costly. In an attempt to produce an accurate but relatively inexpensive method of estimating and updating harvest costs in Montana, we have developed an approach that combines elements of all four approaches described by Horngren et al. (4).

COLLECTING HARVEST COST DATA

We collected cost data associated with harvesting timber in western Montana by presenting 16 scenarios to a targeted population, which included the 9 largest timber-processing companies and independent logging contractors in the state. The scenarios were developed for a range of ecosystem restoration treatments and forest types in western Montana. Logging managers were presented with each silvicultural/harvest prescription, and asked to prepare a cost estimate or "bid" during the interview period. A few respondents requested additional time and returned the completed bids at a later date. The harvest operations were presented as taking place on a treatment unit 40 to 80 acres in size, with average skidding/yarding distances of 600 feet. In a follow-up survey, operators were asked to provide cost estimates for average skidding/yarding distances of 1,200 and 1,800 feet.

Estimates of stump-to-loaded-truck costs were obtained for each prescription applied on terrain suitable for ground-based systems (defined as ≤ 35% slope), and for steeper ground (> 35% slope) requiring skyline systems. These two harvest systems account for the overwhelming majority of timber recovered in the region. Costs were collected for the following specific activities or centers:

- Planning and administration;
- Felling (mechanical felling was designated for ground-based systems, and hand felling for skyline systems);
- Skidding or yarding (rubber-tired skidders with grapples were designated for ground-based skidding systems; a live skyline in the form of a swing yarder was designated for the 600-ft. average yarding distance, while a larger "tower system" was designated for the 1,200- and 1,800-ft. yarding distances);
- Limbing and bucking (whole trees are skidded or yarded to the landing and mechanically delimbed and bucked to length under both ground-based and skyline harvest systems);
- Loading

The approach employed bears most resemblance to the conference method because it involved "gathering analyses and opinions about costs from various knowledgeable people" (6); however, it also uses components of each of the general approaches outlined by Horngren et al. (4). In all cases, the responses were based on the operators' analyses of the proposed harvest operation and their own capabilities. Managers who provided cost estimates in this study were familiar with the operations, processes, and activities required to accomplish the restoration treatments. Managers independently evaluated the proposed operations, and predicted how much of each activity would be necessary to complete the job given their own equipment and personnel, and made estimates based on that knowledge. The cost estimates were derived using some combination of:

- Internal accounting records;
- Precise knowledge of equipment capabilities, personnel, and associated costs;
- Actual costs for similar, recently completed harvest operations.

Developing predictive cost models

Two equations were developed: one for tractor system costs and one for skyline system costs. Stump-to-loaded-truck harvest costs in dollars per green ton were used as the dependent variable in both the tractor and skyline cost equations. Stump-to-loaded-truck costs include felling, limbing and bucking, skidding/yarding, loading, and planning and administration costs. Costs were collected and are expressed in constant 1998 dollars.

The cost equations used key independent variables that had been identified in a previous analysis as important predictors of activity costs (5). Eleven potential independent variables were evaluated in the analysis (**Table 1**). All but one of the independent variables describes the size or amount of material removed from the stand, or the attributes of the remaining stand. The remaining independent variable describes the average skidding/yarding distance required to move the logs from the stump to the landing.

Ordinary least squares regression procedures were used in the analysis (8). Preliminary model specifications were derived using all possible regression procedures, with final equations chosen based upon goodness of fit (adjusted r^2). Equations were examined for violations of statistical assumptions (normality and constant variance) using standard regression diagnostic techniques, such as normal probability plots and outlier analysis (1). Verification of the statistical assumptions is important for valid hypothesis testing to occur, especially given the small sample sizes in this study. Partial regression plots were used to evaluate the curve form of the cost equations (7).

TABLE 1. — Independent variables used in study.

Description	Units
Avg. diameter at breast height removed	Inches
Maximum diameter removed	Inches
Minimum diameter removed	Inches
Avg. diameter of residual stand	Inches
Maximum diameter of residual stand	Inches
Minimum diameter of residual stand	Inches
Trees per acre removed	Number
Trees per acre in residual stand	Number
Volume per acre removed	Green tons
Volume per acre of residual stands	Green tons
Skidding/yarding distance	Feet

TABLE 2. — Tractor skidding cost equation.

Variable	Coefficient (t-statistic)
Average diameter at breast height removed (in.)	-1.272 (-10.14)
Volume per acre removed (tons)	-0.058 (-9.01)
Average skidding distance (ft.)	.0069 (17.22)
Constant	28.04 (22.08)
r^2	.637
Adjusted r^2	.631
Standard error as % of mean	13.4

TABLE 3. — Skyline yarding cost equation.

Variable	Coefficient (t-statistic)
Average diameter at breast height removed (in.)	-1.306 (-4.39)
1/Volume per acre removed (tons)	211.962 (8.77)
Average skidding distance (ft.)	0.0126 (17.95)
Constant	26.63 (10.46)
r^2	.816
Adjusted r^2	.812
Standard error as % of mean	12.2

A repeated measures study design was used in this analysis. Each stand (scenario) was considered an observation, with the logger serving as the repeated measure. This led to a sample size of 16 observations. Tests of significance for the estimated regression coefficients were based on this sample size.

Results

Tractor skidding cost equation

The stump-to-loaded-truck cost equation for the tractor harvest system consists of three significant variables: 1) average diameter of trees removed (range 6 to 10.5 in.); 2) volume per acre removed (range 13 to 125 green tons); and 3) average skidding distance (600, 1,200, and 1,800 ft.) (**Table 2**). The model explained approximately 63 percent of the variation. All independent variables were highly significant, with calculated probability values of < 0.00001, and the estimated regression coefficients have the expected signs.

The coefficient for average diameter indicates that stump-to-truck costs decrease $1.27 per green ton for a 1-inch increase in average diameter removed. The coefficient for volume per acre removed indicates that stump-to-truck costs decrease $.06 per ton for a 1-ton increase in volume per acre removed. The coefficient for average skidding distance indicates that for a 100-foot increase in distance, stump-to-truck costs increase approximately $0.69 per ton.

Skyline Yarding Cost Equation

The equation for estimating stump-to-loaded-truck costs for the skyline yarding system consists of the same variables as the tractor system model: 1) average diameter of trees removed (range 6 to 10.5 in.); 2) volume per acre removed (range 13 to 125 green tons); and 3) average yarding distance (600, 1,200, and 1,800 ft.) (**Table 3**). The skyline yarding model explains approximately 81 percent of the variation in harvest costs. All variables were highly significant, with calculated probability values of < 0.0005. The standard error as a percent of the average stump-to-truck cost is 12.2 percent, indicating that the model error is relatively small.

The coefficients for average diameter and volume per acre removed indicate that as tree size and removal volume increase, stump-to-truck costs decrease. The coefficient for average diameter removed indicates that stump-to-truck costs decrease by $1.31 per green ton for each 1-inch increase in diameter of the material removed. For the range of harvest volumes examined, as volume per acre removed decreases, costs increase on average $0.13 per green ton. The coefficient for the average yarding distance indicates that as the yarding distance increases, so do the stump-to-truck costs. From a marginal standpoint, stump-to-truck costs increase approximately $1.26 per ton for every 100-foot increase in skyline yarding distance.

Discussion

The process presented here offers an inexpensive approach to developing a substantial database of costs, given experienced operators and cost and production records on which to base estimates. The data can be used to produce regression equations with good predictive capability. If the cost of gathering data were not a factor, an industrial engineering approach involving detailed time-and-motion studies might provide data and models with somewhat greater accuracy than achieved here, certainly for particular pieces and configurations of equipment. Time-and-motion studies may also be the most precise method to analyze specific operations for factors that affect productivity. For example, how might modest changes in slope influence the productivity of a specific piece of skidding equipment? Further, time-and-motion studies are a key aspect in the development and proper evaluation of new equipment or mixes of equipment.

However, under even the best of circumstances it may be impossible to exceed some given level of accuracy in predicting timber harvest costs, regardless of approach. For example, differences in site conditions (e.g., rockiness, downed timber, soil moisture) and stand conditions (e.g., range and proportion of tree sizes, patterns of tree occurrence) impact harvest costs, but are not measured precisely or consistently. Variables such as weather conditions are virtually impossible to predict. Yet all of these factors work to decrease the quality of model estimates.

The fact that independent contractors do virtually all of the logging in this region also limits the precision with which actual harvest costs can be predicted. Given this dominance of independent contractors, cost estimates based on the average logging industry infrastructure in the region may well be more useful than precise estimates of harvest costs for specific equipment configurations.

General knowledge concerning harvest costs is useful to an agency such as the USDA Forest Service, both for making management decisions and for strategic planning. However, detailed knowledge of costs by equipment type may not be particularly useful because of the wide array and configurations of equipment used, and the general inability to determine in advance the exact equipment an operator might use. Given that a wide variety of equipment can perform a given task, such as felling trees, the landowner or agency generally does not have a preference as to what equipment is used. Also, since most harvest operations are bid or negotiated based on the perceived cost of the operation, logging industry perceived cost (as developed in this study) can be a better estimate of the cost to the landowner than costs based on a detailed study of the logging process.

The proposed approach offers a means to quickly estimate costs of implementing new and different prescriptions, such as those employed for ecological restoration or fire hazard reduction purposes. These types of estimates, sometimes outside the range of normal operating conditions, have proven to be adequate to answer strategic questions related to broadscale impacts (5).

The approach used in this study depends on respondents providing accurate information. The fact that a substantial number of operators were independently surveyed in itself provides a cross check on responses. From the respondent's point of view, there were strong incentives to provide accurate information. Providing harvest estimates that were too low would lead the agency to develop timber harvest projects that were not financially viable, and providing costs that were too high would cause the agency to forgo developing projects that could potentially provide employment and income to the operators.

The approach described here offers an inexpensive means of estimating harvest costs, provides cost equations with good predictive capability, and can be expanded inexpensively to develop data on new and varied prescriptions and equipment mixes. However, we do not propose that a system to estimate harvest costs would rely entirely on operator inputs. Cost estimates should be verified periodically using both published data and detailed time-and-motion studies.

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