United States Department of Agriculture

OpCost: an Open-Source System for Estimating Costs of Stand-Level Forest Operations

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Forest Service

Pacific Northwest Research Station

General Technical Report PNW-GTR-960

October 2017

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Published in cooperation with the University of Idaho.

Cover photo: Log deck resulting from a mechanical forest thinning operation in Washington Douglas-fir forest. Photo by Robert Keefe.

Abstract

Bell, Conor K.; Keefe, Robert F.; Fried, Jeremy S. 2017. OpCost: an open-source system for estimating costs of stand-level forest operations. Gen. Tech. Rep. PNW-GTR-960. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station 23 p.

This report describes and documents the OpCost forest operations cost model, a key component of the BioSum analysis framework. OpCost is available in two editions: as a callable module for use with BioSum, and in a stand-alone edition that can be run directly from R. OpCost model logic and assumptions for this open-source tool are explained, references to the literature used in all of the submodels included in OpCost are provided, and guidance is offered on how to change the default hourly machine rates associated with overall logging cost calculations. OpCost enhancements such as cost component breakout, and identifying the least-cost harvest system, are also described and explained.

Keywords: Harvest systems modeling, mechanical fuel treatment logging cost estimation calculator.

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Introduction

Estimating costs of forest operations is essential for evaluating the economic feasibility of forest management alternatives, especially those involving partial harvest conducted as a component of forest restoration, where costs may be a large fraction of, or exceed, revenues from sales of harvested wood. The Fuels Reduction Cost Simulator (FRCS) (Fight et al. 2006), the development of which began over two decades ago, sought to address this need with a multisheet Excel®[1] spreadsheet tool into which users could enter parameters associated with stand conditions and the material to be harvested as part of fuel treatment operations. In FRCS, and in OpCost, the user chooses a harvest system appropriate for a given site and stand conditions, specifies the "cut list" that results from applying a silvicultural prescription designed to reduce fuel loadings, and obtains estimated costs associated with implementation of that prescription. As interest grew in obtaining treatment cost estimates for large numbers of stands treated via a range of alternative prescriptions simulated on the landscape simultaneously, as implemented in the BioSum model (Fried et al. 2016) and other approaches to modeling landscape-scale operational logistics (Jacobson et al. 2016), the inherent limitations of the spreadsheet-based paradigm for simulating operational costs became evident. Operations foresters at the University of Idaho, with support from the Joint Fire Sciences Program, undertook a revision and restructuring of the FRCS model. The products of their efforts include the OpCost forest operations cost model, programmed in R, and a validation study that compared OpCost estimates with expert judgments collected via a formally designed survey of logging professionals (Bell et al. 2017). In addition to updating currently available production functions and cost estimates based on recent literature, OpCost includes some additional harvest system capabilities, such as simulation of shovel logging, and provides a more reliable interface to BioSum.

OpCost incorporates production rates from over 85 studies, many with a vintage more recent than the last version of FRCS, released in 2009, of both manual and mechanized operational systems. One edition of the model, OpCost BioSum Edition (BE), is distributed with the BioSum software. OpCost BE is a callable code package, running under R (R Development Core Team 2016), that tightly integrates with BioSum to estimate the costs for modeled forest harvest operations simulated under that analysis framework. The other edition, OpCost Stand-alone Edition (SE), can be run directly from the R development environment. OpCost is driven by essentially the same variables used as inputs to its predecessor, FRCS. For trees simulated as

[1] The use of trade or firm names in this publication are for reader information and do not imply endorsement of the U.S. Department of Agriculture of any product or service.

harvested, 35 variables account the for the average volume per tree, number of trees harvested per acre, hardwood fraction, merchantable volume as a percentage of total volume and wood density for each of three user-defined tree size classes, along with trees per acre and average tree volume of small ("brush cut" size, in FRCS parlance) trees that are cut but not used. Other inputs include slope and average distance to the nearest landing and, for small and large log trees, the percentage of wood volume transported to the landing that will be chipped owing to its derivation from trees of submerchantable size or noncommercial species. Average travel time, in hours, required to move-in a harvest system equipment component (e.g., a skidder) to the harvest site and operation size, in acres, are required to estimate move-in costs on a per-acre basis.

OpCost greatly streamlines workflow of a batch operation relative to FRCS by eliminating the need to export data to Microsoft (MS) Excel as an intermediate step prior to cost estimation. OpCost is also designed to operate in batch mode, but reads inputs from and writes outputs to MS Access database tables, making it equally easy for users to estimate costs for one stand and treatment or thousands of stands and dozens of treatment alternatives. The integration of OpCost with BioSum produces cost estimates for each analyst-specified combination of silvicultural prescription and harvest system on each inventory plot modeled in BioSum. This facilitates estimates of cost effectiveness for the wide range of fuel treatments on managed forests in the Western United States (e.g., Jain et al. 2012). The system can also estimate harvest costs for implementing any silvicultural prescription, not just those intended to reduce hazardous fuels.

OpCost Framework Overview

Production functions in OpCost use, as inputs, the estimated amount of removed or altered material within forest stands based on summary metrics from simulated silvicultural prescriptions that generate a "cut list" in the Forest Vegetation Simulator (FVS) (Dixon 2002) format. These predict, on a per-acre basis, the time and expense required to harvest and process wood volume. In essence, OpCost is an equation filtering and aggregation engine that, considering the specifics of a stand, silvicultural treatment to be modeled, and harvest system to be implemented, applies several possible equations extracted from peer-reviewed forest operations literature. These are typically based on past elemental time analysis and work sampling studies that are identified as applicable to the stand and site under consideration; OpCost computes the average of the predictions of all applicable equations. By using the regression equations from descriptive studies, OpCost can predict the production rates of the equipment within certain conditions. Applicability is determined by whether an

equation is eliminated from consideration by "rejection" criteria that differ among equations for a given harvesting, extraction, or processing machine. Examples of rejection criteria, which are evaluated for each operation based on whether the OpCost inputs fall within the acceptable range for an equation, include slope, average volume per tree, average distance to landing, whether hardwoods are part of the harvest, average tree diameter, average tree weight, and harvested trees per acre. Nonrejected equations for each machine used in a harvest system advance to the next computation phase. The rejection criteria are based on the range of data over which original studies were evaluated, in order to avoid extrapolation of production or cost functions beyond the range of their source data and intended application.

Estimating Machine Time Required

A harvest system can be thought of as a collection of the equipment, or machines, and labor required to implement operations under that system. For example, a cable manual whole-tree system typically operates on steep slopes and, after manual tree felling by a sawyer, brings entire trees, including bole, branches and top (as opposed to previously bucked logs) to the landing using a yarder. At the landing, whole trees are processed into merchantable logs and nonmerchantable residues with a processor, which may be either a stroke-boom delimber or danglehead processor. Logs are then loaded onto log trucks with a loader and residues are chipped and blown into a chip van. Thus, this system involves five machines: manual felling (sawyer with a chainsaw), yarder, processor, loader, and chipper, each of which may have up to a dozen or more published equations that could be used to predict the time required per unit of trees or volume handled. Given the diversity of study purposes and locales behind the published equations, and differences in the factors affecting costs for different machines, tree units differ among machines and among studies. Wood characteristics tracked by the model may be expressed on a volume or mass basis, depending on the relevant production function and study. Volumes may be expressed in cubic feet, board feet, cords or cubic meters, and mass values may be in pounds or kilograms. Times are summed across size classes, and these sums are then combined into the mean time in hours per acre.

Estimating Machine Cost

Once total machine working time has been adjusted into hours per acre, machine cost per acre is computed as the product of hours and machine cost rates, which are based on conventional cost control processes (Matthews 1942). Calculations occur in productive machine-hours (PMH) and following convention in forest operations studies, a utilization rate is assigned to distinguish between production and delay time. Because OpCost generates

estimates at a stand level, without regard to stand location, it cannot assign location-specific move-in costs associated with each machine's use. However, when using OpCost within a BioSum analysis, per-acre move-in costs can be accounted for based on travel time to wood processing facilities (a parameter calculated as part of the BioSum workflow and a viable proxy for move-in time) and assumed stand area undergoing treatment. Move-in costs could also be affected by the locations of scheduled work in a particular year; however, this level of detail is beyond the scope of OpCost and BioSum and is not addressed. Wherever available, machine rates include fixed and variable costs associated with owning and operating the equipment. These have been updated with current estimates (Dodson et al. 2015). Default machine cost rates, developed for the Pacific Northwest region, are supplied in the OpCost code, but can be changed by the user, if desired and necessary, via a straightforward text edit to the open source model code (for OpCost BE) or to the appropriate input table (for OpCost SE).

Estimating Harvest System Cost

After machine cost estimates are complete, harvest cost per acre can be calculated as the sum of each of the predicted machine-specific treatment costs associated with the harvest system working in the BioSum-supplied site and stand conditions. For the cable manual whole-tree system example, this would be the sum of treatment costs per acre for sawyer, yarder and carriage combination, processor, loader, and chipper. Treatment cost accounts for both the machine rates and the production rates for each piece of equipment. Production rates are typically expressed in tons per PMH or thousand board feet (MBF) per PMH and provide predictions of the total treatment time required by each piece of equipment to treat volume removed per acre. See, for example, Keefe et al. (2014) for further description of the relationship between machine rates, production rates, and treatment costs. Move-in cost, derived from the number of machines transported to the harvest site and assumptions that account for delays in setting up equipment, when applicable, is added to obtain the final harvest cost reported in the table OpCost_Output. That table also contains calculated move-in cost in a separate column to better inform the analyst wishing to consider, for example, savings that might accrue from consolidating forest operations.

Enhancements

A significant enhancement compared to FRCS is the simultaneous estimation of costs for multiple, potentially more cost-efficient harvest systems. These estimates can be compared to the costs of the analyst-specified harvest system, replacing

them if desired. By default, cost estimates for the lowest cost harvest system are output to a table called "OpCost_Ideal_Output." Users wishing to prevent the creation of this table, thus slightly shortening execution time, can change the "1" to a "0" in the following OpCost statement: idealTable←1 (currently line 20 in version 8.7.9) of the executable code.

Another new feature is the reporting of chipping costs in a separate column in both the OpCost_Output and OpCost_ Ideal_Output tables. This could be useful when considering alternative approaches to disposal of harvest residues, as when a treatment leaves residues at the landing for collection as firewood or later burning—chipping cost might then be deducted from the harvest cost.

How It Works, in Detail

This section describes OpCost processing in greater detail, including the specific inputs and intermediate processing steps. This information is current as of version 8.7.9.

OpCost predicts operations costs for 11 harvest systems. Each system can be thought of as an integrated sequence of activities using several pieces of equipment, operating in a coordinated fashion, to move wood from trees to trucks, while accomplishing management objectives. For example, a harvest system may be used to transform a forest stand in terms of its density, tree species and size distribution, surface vegetation and fuels, and emergent properties such as forest health, resistance to fire, and overall resilience that derive from these. In addition to differences in how harvested material is felled and transported, harvest systems differ in the materials that are collected for utilization. OpCost provides for five harvest system categories to reflect these differences when estimating operations costs (table 1). The 11 systems included in OpCost (table 2) cover nearly all forest management activities that involve mechanical fuel treatment and other harvests. To estimate the cost of applying these systems to implement particular prescriptions on specific stands, OpCost relies on 124 equations extracted from 82 published articles (table 3) covering all 11 machine types used in these 11 harvest systems.

For each equipment type, the available equations differ in the inputs that are required, so the "independent variables" column in table 3 is an exhaustive list of attributes used by any of the equations in the equipment category. The meaning of most of these attributes is straightforward. Piece volume is average volume per tree; total volume is volume per acre. Depending on the equation, species group is ultimately either a binary descriptor indicating whether hardwoods comprise more than 1 percent of the harvested material or the percentage of volume that is in hardwoods.

Table 1—Utilization of wood in tops and limbs varied by harvest system category and slope

Harvest system category	Slope	Outcome for tops and limbs
1	Low	Left in the woods
2	Low	Forwarded to landing for chipping
3	High	Left in the woods
4	Any	Except for large log trees, forwarded to landing for chipping
5	Any	Forwarded to landing for chipping only when size is submerchantable or species is noncommercial

Table 2—Harvest systems options available in the OpCost model and the equipment types used in each system

Harvest system name	Equipment types used	Harvest system category
Ground-based manual whole tree	Sawyer, skidder, processor, loader, chipper	2
Ground-based mechanical whole tree	Feller-buncher, skidder, processor, loader, chipper	2
Ground-based cut to length (CTL)	CTL harvester, forwarder, loader, chipper	1
Ground-based manual log	Sawyer, forwarder, loader, chipper	1
Cable manual whole tree	Sawyer, yarder, processor, loader, chipper	4
Cable manual whole tree/log	Sawyer, feller-buncher, processor, loader, chipper Note: all large trees are assumed to be manually bucked into logs prior to yarding	5
Cable manual log	Sawyer, yarder, loader, chipper	3
Cable CTL	CTL harvester, yarder, loader, chipper	1
Helicopter manual whole tree	Helicopter, sawyer, processor, loader, chipper	3
Helicopter CTL	Helicopter, CTL harvester, loader, chipper	1
Shovel manual whole tree	Shovel, sawyer, processor, loader, chipper	4

Table 3—OpCost source of equations to estimate machine time requirements for forest harvest operations by machine type, and input variables equations draw from as independent variables for predicting machine time per unit tree volume or mass

References for production equations by machine type	Required independent variables
Sawyer:	
Behjou and Majnounian 2009	Diameter at breast height (d.b.h.)
Ghaffariyan et al. 2012	Total volume
Hartsough et al. 2001	Piece volume
Klepac et al. 2011	Distance between trees
Kluender and Stokes 1996	Slope
Lortz et al. 1997	
Visser and Spinelli 2012	
Wang et al. 2004	
Cut-to-length (CTL) harvester:	
Acuna and Kellogg 2013	D.b.h.
Adebayo et al. 2007	Slope
Berhongaray et al. 2013	Trees/acre
Bolding et al. 2002	Total volume
Bolding and Lanford 2001	Piece volume
Drews et al. 2001	Species group
Eliasson 1999	Distance between trees
Hiesl 2013	
Hiesl and Benjamin 2012	
Jiroušek et al. 2007	
Kärhäet et al. 2004	
Jiroušek et al. 2007	
Keegan et al. 2002	
Klepac et al. 2006	
Klepac et al. 2011	
Numinen et al. 2006	
Visser and Spinelli 2012	
Skidder:	
Adebayoet al. 2007	
Bolding et al. 2002	D.b.h.
Boswell 1998	Piece volume
Ghaffariyan et al. 2012	Species group
Hiesl and Benjamin 2012	One-way yarding distance
Keegan et al. 2002	Total volume
Kluender and Stokes 1996	Trees/acre

Table 3—OpCost source of equations to estimate machine time requirements for forest harvest operations by machine type, and input variables equations draw from as independent variables for predicting machine time per unit tree volume or mass (continued)

References for production equations by machine type	Required independent variables
Wang et al. 2004	Slope
Feller-buncher:	D.b.h.
Adebayo et al. 2007	Distance between trees
Berhongaray et al. 2013	Piece volume
Bolding and Lanford 2001	Trees/acre
Boswell 2001	Species group
Dykstra 1976	Trees/acre
Hartsough et al. 1997	Slope
Hartsough et al. 1997	
Hartsough et al. 2001	
Hiesl 2013	
Hiesl and Benjamin 2012	
Kärhä et al. 2004	
Kluender and Stokes 1996	
Spinelli et al. 2007	
Wang et al. 2004	
Helicopter:	
Christian and Brackley 2007	Piece weight
Dykstra 1976	One-way yarding distance
Flatten 1991	Elevation
Flatten 1991	Piece volume
	Trees/acre
Forwarder:	
Acuna and Kellogg 2013	One-way yarding distance
Bolding et al. 2002	Piece volume
Bolding and Lanford 2001	Slope
Drews et al. 2001	Trees/acre
Dykstra 1976	Total volume
Hiesl 2013	D.b.h.
Jiroušek et al. 2007	Weight
Jiroušek et al. 2007	
Kluender and Stokes 1996	
Numinen et al. 2006	
Sirén and Aaltio 2003	

Table 3—OpCost source of equations to estimate machine time requirements for forest harvest operations by machine type, and input variables equations draw from as independent variables for predicting machine time per unit tree volume or mass (continued)

References for production equations by machine type	Required independent variables
Cable:	
Drews et al. 2001	Trees/acre
Aubuchon 1982	Slope
Dykstra 1976	Piece volume
Boswell 2001	Piece weight
LeDoux 1987	One-way yarding distance
Hartsough et al. 2001	
Huyler and LeDoux 1997	
Chipper:	
Bolding et al. 2002	Piece volume
Bolding and Lanford 2001	Species group
Cuchet 2004	D.b.h.
Spinelli and Magagnotti 2014	
Shovel:	
Fisher 1986	One-way yarding distance
Sessions and Boston 2013	Elevation
Wang and Haarlaa 2002	Piece volume
	Piece volume
	Trees/acre
	Weight
Stroke-boom delimber:	
Ghaffariyan et al. 2012	Piece volume
Spinelli and Hartsough 2006	D.b.h.
Hiesl 2013	Species group
Spinelli and Magagnotti 2010	

Inputs

BioSum initiates an instance of R, passing to it the OpCost BE filename and the name of an Access file that contains all input data in a table named opcost_input. This table consists of 36 attributes per stand (table 4). In general, but with a few exceptions for size classes, where some are not needed, there is a quintet of harvested tree descriptors for each of four size classes defined by the user in BioSum, plus a few site descriptors. Note that the size class definitions themselves (in terms of minimum and maximum diameter at breast height [d.b.h.]) are not passed to, or needed by, OpCost. The four size classes are brush cut (BC), chip trees (CT), small log trees (SLT) and large log trees (LLT). Each of these size classes is determined by the analyst. The BC trees are harvested but not used, so OpCost accounts only for the costs of their felling. The CT boles are assumed to be used as "dirty" chips (with bark not removed before chipping) and have no merchantable value that would exceed their value as dirty chips; limbs are also used as chips when whole-tree harvest systems are used. To account for the costs of chipping trees in the SLT and LLT size classes that are noncommercial species not used to produce merchantable wood products, inputs to OpCost include the percent of log volume that would be chipped. These "chip percent" parameters are provided for each of three groups of harvest system categories, because the chip percentages vary depending on exactly what material (e.g., boles-only or tops and limbs also) gets transported to the landing, for example, depending on system, size and species. Tops and limbs that harvest systems do not bring to the landing are assumed to be left in the woods and incur no chipping costs. Note that average tree volumes provided as inputs to OpCost are total volumes, including tops and limbs.

Transformations

A comparison of the variables listed in table 3 (required input variables) and table 4 (OpCost inputs) shows that while most are aligned, there are some required variables not provided by BioSum. As each stand is processed, OpCost effects transformations to ensure that the input requirements for all 124 equations can be met. For example, OpCost estimates average d.b.h., which is required by at least some production functions for most equipment types, by inverting formulas associated with common log scale rules such as the international ¼-inch rule (Grosenbaugh 1952) and Scribner's Decimal C (Bruce and Schumacher 1950), to predict d.b.h. from BioSum-supplied average volume per tree. In several cases, it is necessary to estimate average intertree distance (which is required by at least some of the sawyer, CTL harvester, and feller-buncher equations) from trees per acre (TPA) supplied by BioSum. Mean inter-tree distance is estimated from TPA as follows:

$$\text{Intertree distance} = \sqrt{(43560/\text{TPA})}$$

Because some equations estimate time required per unit mass, OpCost calculates mass per acre, by tree size class and in total, by multiplying BioSum-supplied average

Table 4—OpCost inputs and what they mean

Column	Input Item	Description
1	Stand	Stand identifier (condition id + rxPackage + rx + rxCycle)
2	Percent slope	Slope
3	One-way yarding distance	Distance in feet between volume centroid of the stand and nearest road
4	YearCostCalc	Year of harvest (used only in OpCost stand-alone edition)
5	Project elevation	Stand elevation in feet above mean sea level
6	Harvesting system	Name of harvest system
7	Chip trees per acre	Trees per acre (TPA) of chip trees
8	Chip trees Merch As Pct Of Total	Percentage of chip tree volume in merchantable-sized wood (used for harvest systems that do not recover tops and limbs)
9	Chip trees average volume(ft^3)	TPA weighted average of total volume
10	Chip trees average density (lb/ft^3)	TPA and volume weighted average wood density of all chip trees
11	Chip tree hardwood percent	TPA and volume weighted percentage of chip tree volume that is in hardwoods
12	Small log trees per acre	TPA of small log trees
13	Small log trees Merch As Pct Of Total	Percentage of small log volume in merchantable-sized wood
14	Small log trees ChipPct_Cat1_3	Percentage of harvested small log volume that will be chipped under harvest systems in category 1 or 3
15	Small log trees ChipPct_Cat2_4	Percentage of harvested small log volume that will be chipped under harvest systems in category 2 or 4
16	Small log trees ChipPct_Cat5	Percentage of harvested small log volume that will be chipped under harvest systems in category 5
17	Small log trees total average volume(ft^3)	TPA weighted average total volume per small log tree
18	Small log trees average density(lb/ft^3)	TPA and volume weighted average wood density of small log tree volume
19	Small log trees hardwood percent	TPA and volume weighted percentage of small log tree volume that is in hardwoods
20	Large log trees per acre	TPA of large log trees
21	Large log trees Merch As Pct Of Total	Percentage of large log tree volume in merchantable-sized wood
22	Large log trees ChipPct_Cat1_3_4	Percentage of harvested large log tree volume that will be chipped under harvest systems in category 1 or 3 or 4
23	Large log trees ChipPct_Cat2	Percentage of harvested large log tree volume that will be chipped under harvest systems in category 2
24	Large log trees ChipPct_Cat5	Percentage of harvested large log tree volume that will be chipped under harvest systems in category 5
25	Large log trees total average vol(ft^3)	TPA weighted average total volume per large log tree
26	Large log trees average density(lb/ft^3)	TPA and volume weighted average wood density of all the large log tree volume
27	Large log trees hardwood percent	TPA and volume weighted percentage of large log tree volume that is in hardwoods
28	BrushCutTPA	TPA of brush cut trees
29	BrushCutAvgVol	TPA weighted average bole+branch volume of brush cut trees
30	RxPackage_Rx_RxCycle	Code indicating silvicultural sequence, prescription and Forest Vegetation Simuator cycle under which trees were harvested
31	BioSum_cond_id	Needed for table joins
32	Rxpackage	Needed for table joins
33	rx	Needed for table joins
34	rxcycle	Needed for table joins
35	Move-in hours	Time required to move in and setup logging equipment
36	Harvest area assumed acres	Area assumed for the size of the harvest operation

wood density by average tree volume and TPA. Depending on the referenced equations used, some volumes are converted to cubic feet, board feet, or cords per acre. All volumes and masses are also converted to metric units (cubic meters per hectare or kilograms per hectare) to fulfill the requirements of equations defined in metric units.

Filtering

When processing each stand, OpCost applies the rejection criteria associated with each of the 124 equipment equations to eliminate equations deemed unsuitable for estimating costs for that stand. Typically, these rejection criteria are derived from the range of an attribute reflected in the empirical data on which an equation was fit. Any of the attributes may be the basis for rejection criteria. For CTL harvesters and feller-bunchers, d.b.h. is an important filter; for yarders, distance to landing and slope might be attributes with rejection criteria, but the criteria will differ among equipment types and among equations for a given equipment type, thus the sets of equations used for any two stands that are in some respects similar, may still differ.

Size Class Specific Versus Total/Average

Equations differ as to whether or not they take stand-level- or size-class-specific inputs, even for a given equipment type. For those that operate with individual size classes (e.g., CT, SLT, and LLT), harvested tree descriptors such as average volume and TPA are processed for a specific size class to obtain equipment time associated with that size class. Ultimately, the equipment times for all size classes are summed. With mixed systems, for example, when only large log trees are manually felled, sawyer equations would use only the LLT descriptors. Because the requirements differ among equations, OpCost calculates overall stand averages and totals for all harvested trees, as noted under “Transformations” above, so that these are available for the equations that rely on them.

OpCost Workflow

For a given equipment type, OpCost calls a machine-specific function. For a yarder time estimate, for example, it would call the yarder function, passing two arguments: the input variables generated by BioSum via the opcost_input table and the list of candidate production functions for that equipment. Parsing each opcost_input record, that function would reject inappropriate yarder equations, create the necessary transformed attributes, estimate yarder times per unit of material for all the appropriate equations, and adjust time per tree unit to time per acre for each tree size class separately, if necessary. It would then sum across size classes, compute the average over estimates from all yarder equations, multiply the estimated time per acre by yarder unit cost in dollars per hour, and return that cost component to be used when adding up the cost of all machines used on that stand, at that time, with that harvest system.

When using OpCost SE, harvest year can be included as an input and optionally, if a discount (interest) rate is provided, harvest cost estimates can be expressed in present or future value terms. When using OpCost BE with BioSum, discounting and inflation considerations are handled within the BioSum modeling framework.

Putting It All together

Figure 1 summarizes the seven major processing steps that occur within OpCost to compute the multiple components of harvest cost and combine them into an estimate of complete harvest cost per acre. Model output is deterministic in that a given set of stand inputs will always produce the same results as long as the same forest vegitation simulator (FVS) stand projection (output) data are included. Note that, apart from BioSum, users sometimes choose to run FVS in a stochastic mode. Thus, OpCost users that repeat growth and yield predictions for the same stand multiple times in FVS prior to postprocessing with OpCost should expect that projected stand conditions may differ owing to inclusion of random numbers in underlying FVS code. This, in turn, may result in variability among associated OpCost treatment cost estimates.

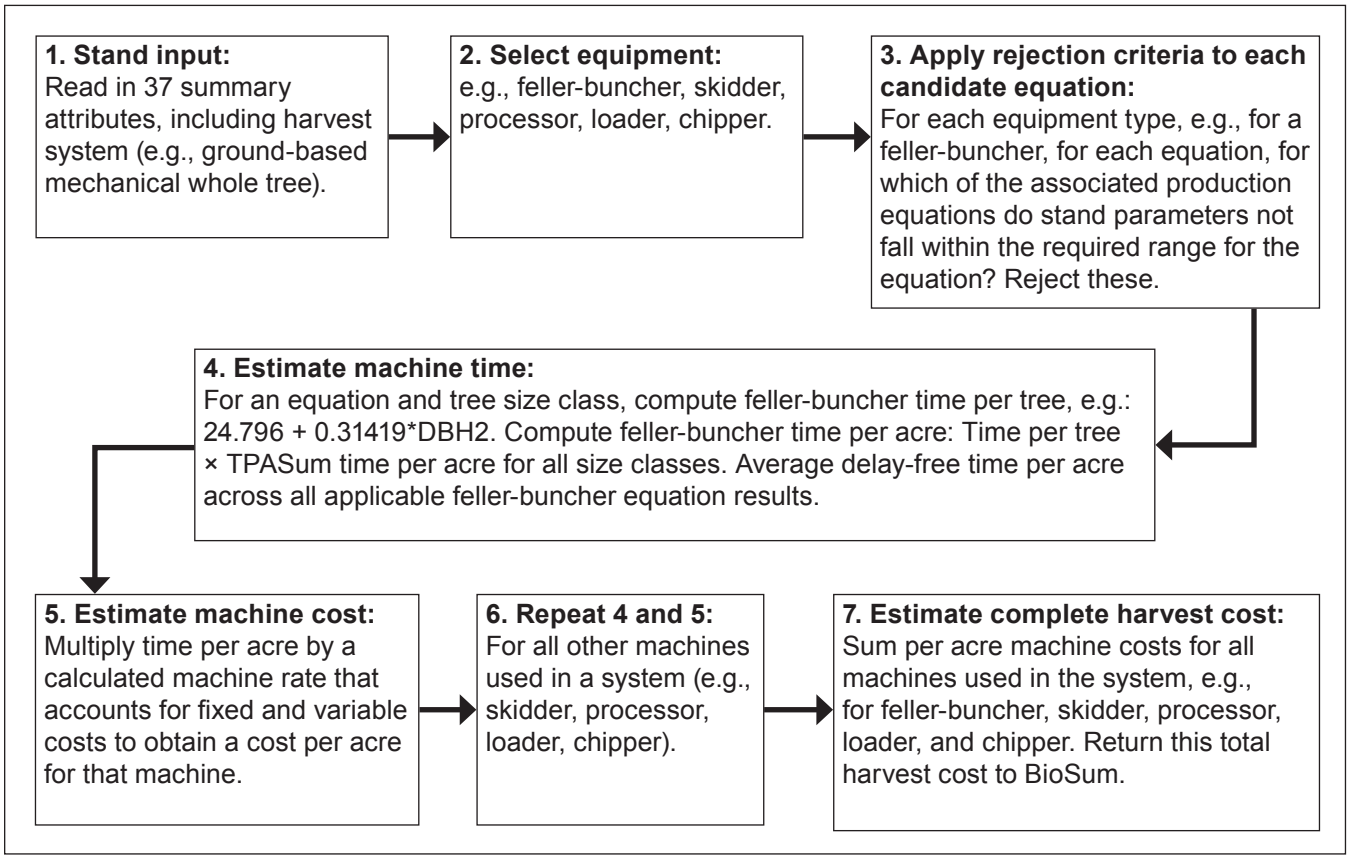

Figure 1—Example of workflow within OpCost to estimate complete harvest cost for a stand harvested via ground-based mechanical whole-tree harvest system.

OpCost Stand-Alone Edition (SE)

OpCost SE is designed to operate without BioSum, and relies on an installed version of R 3.0 or greater (R Development Core Team 2016), with the R (language) Open Database Connectivity (RODBC) (Ripley and Lapsley 2016), Shiny (Chang et al. 2016), and ggplot2 (Wickham 2009) packages installed and loaded. There are three required script files that are available for download, and all three files should be saved to a single reference folder in the analyst's computer. The files are called ui.r, server.r, and OpCostShiny.r. These files are available at the following URL: http://www.uidahoforestoperations.com/forest-operations-modeling.html. Each R script needs to be stored in the same directory on the user's computer so the server code can locate the other files. After the files have been loaded, they are then available to open in the R environment using either the R console or a development environment such as RStudio. The user then runs the Shiny-based OpCost Graphical User Interface in R and the app will appear in the computer's default web browser (tested with Internet Explorer) allowing for a simple, interactive and intuitive user interface. The inputs are the same as for OpCost BE and can be stored in either comma or space delimited text files.

Once the application is open in the browser window, the user begins by navigating to and selecting the input file. A progress bar provides feedback as this data is loaded and processed, typically within seconds. When the progress bar achieves 100 percent, the estimated costs per acre using the harvest system chosen by the user will appear in a table, with one row per stand ID and prescription year. Each table generated by OpCost may be selected and copied or downloaded as a text file using the table buttons. After the table appears, the user also has the option of selecting the "ideal" table, present cost of future treatments, and ideal present costs of future treatments. The present cost and ideal present cost tables contain the discounted costs of harvest prescribed for a future year. The analyst also has the ability to select a different state, with different assumed machine rates, or can designate custom machine rates using the third tab of the interface by selecting the designated check box, which activates the custom machine rate table (figs. 2, 3, and 4).

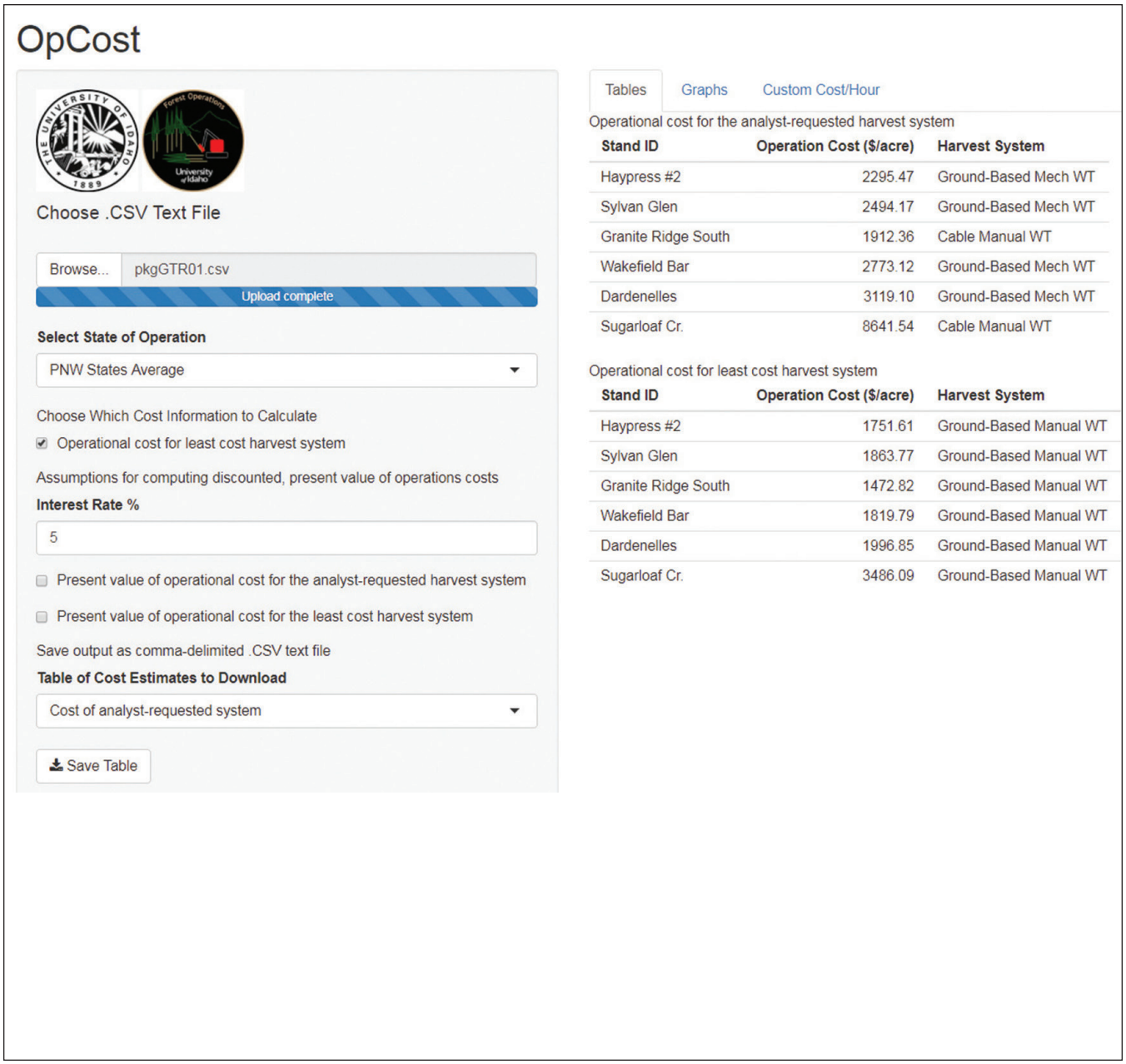

Figure 2—Initial “Tables” page in OpCost stand-alone.

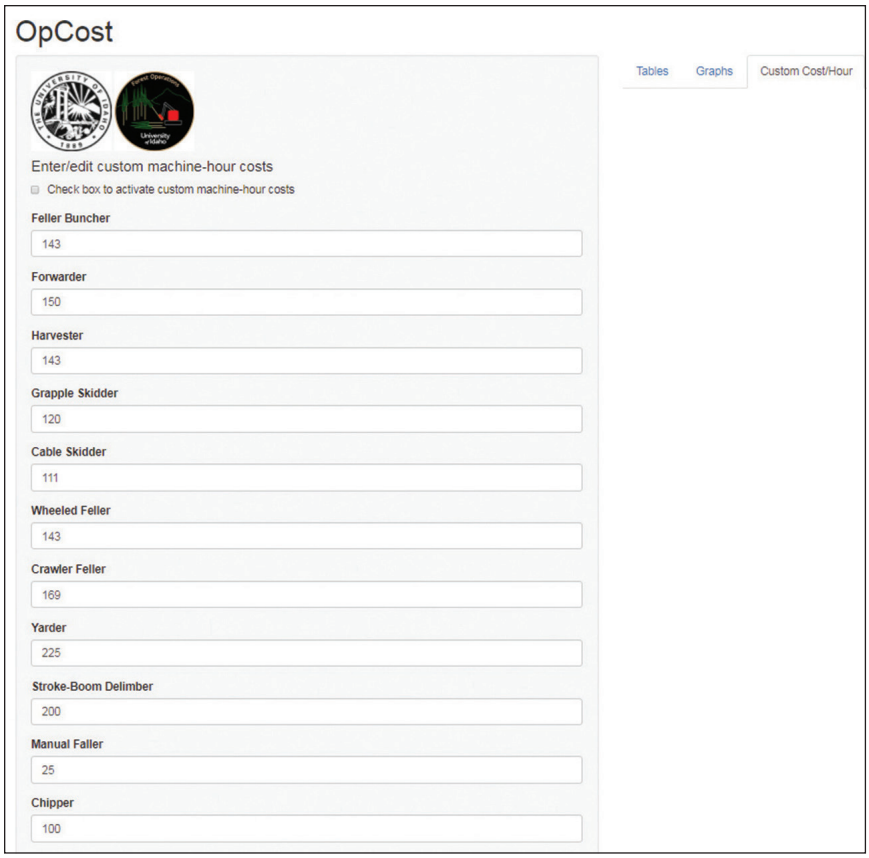

Figure 3—The "Custom Cost" page in OpCost stand-alone edition.

Each loaded table actively updates as an analyst adjusts prescription year or machine rates, streamlining the process for experimenting with different scenarios. After creating these tables, the analyst can proceed to the figures page where each of the tables previously created can be displayed graphically. The figures page also provides a graphical cost comparison of the analyst-defined harvest system and the system estimated by OpCost as the lowest cost alternative. Note that figures will only be viewable after tables have been created. Figures can be copied and pasted to a separate document, or saved to a disk, using the menu options that appear when right-clicking on the image.

To run another set of stand operations without starting a new session, save the output data, if desired, before loading a new dataset. **OpCost SE does not automatically save outputs** to files or maintain previous estimates in memory, so any information from the previous analysis will be overwritten when new data are loaded. All output tables and figures will also be lost if exiting the program without first saving these to disk.

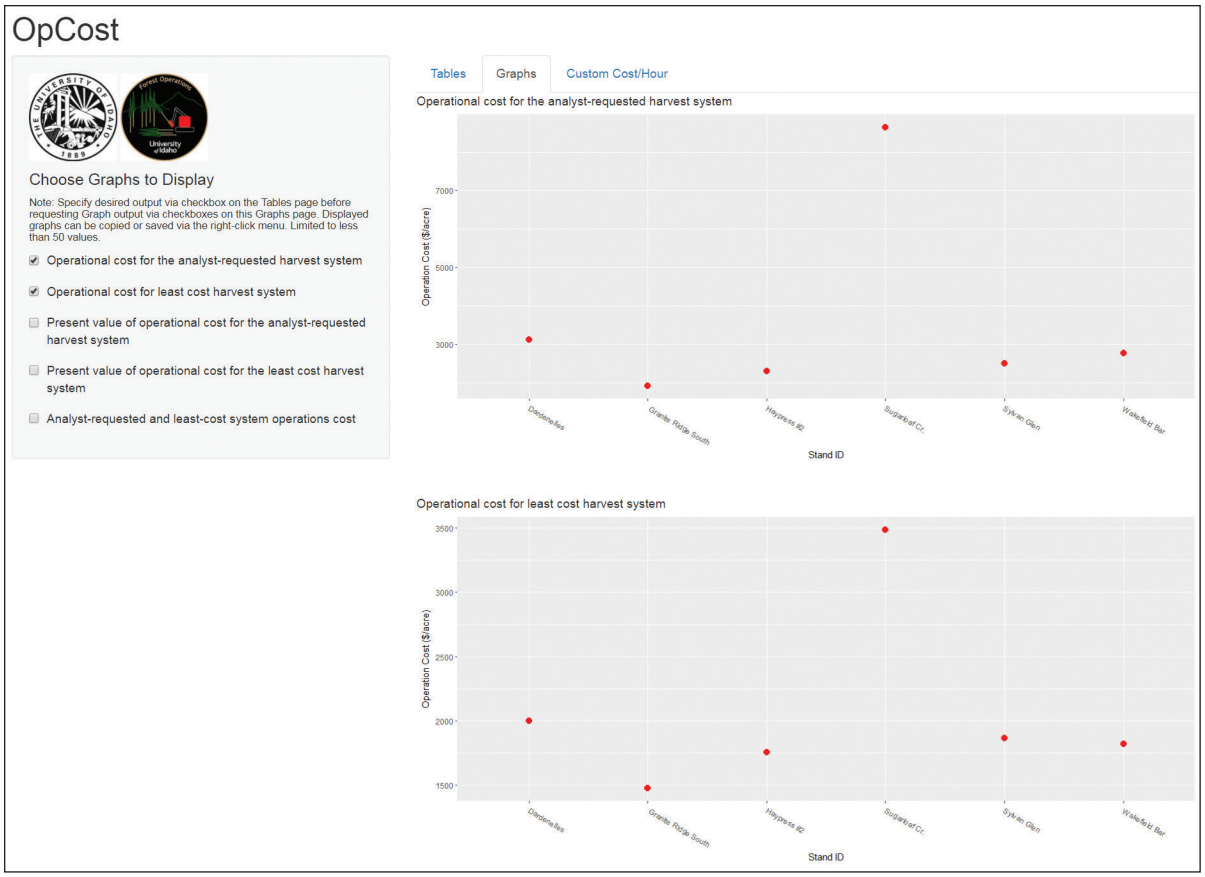

Figure 4—The “Plots” page of the OpCost stand-alone edition.

Future Directions

OpCost's adaptable design enables it to handle a wide variety of systems and to accommodate new systems yet to be developed. Development is underway to enable production rates for new kinds of equipment to be implemented by entering the parameter and predictor variables associated with production and machine rates for new equipment and systems into a preformatted Excel table. The production function supplied should include output in total treatment time (delay-free productive machine hours), expressed on a per-acre basis. Users should also supply the key components of equipment machine rates: purchase price, utilization rate, etc (See, e.g., Brinker et al. 2002 for a description of machine rate calculations). The user-supplied production function parameters and machine rates will be incorporated into system-level logging cost predictions as described in, for example, Keefe et al. (2014). A sample Excel table and details on how this table will be accessed by OpCost will be documented in the release notes accompanying a future OpCost version.

One of the great benefits of providing OpCost in the open-source R framework is that it facilitates coordinated growth, development, and testing by a more expansive set of users than did earlier Excel, and Visual Basic for Applications or VBA-based versions of FRCS and related models. We anticipate making OpCost available as part of a package of R functions in the future in order to foster widespread distribution and use, especially for automated landscape-scale analyses. In its current incarnation, OpCost relies on stand-level FVS summaries of harvested trees. We envision refinements to the model that would base cost estimates on the full FVS tree list data, instead of summary metrics, potentially leading to greater accuracy and higher resolution simulation of operational logistics.

Acknowledgments

Terrie Jain and Nicholas Crookston from the U.S. Forest Service Rocky Mountain Research Station provided valuable assistance in the development of OpCost. We appreciate the useful suggestions contributed by reviewers Beth Dodson, Sandor Toth, and Kevin Boston that improved this report, and the extensive quality assurance testing by Portland State University Dynamic Ecosystems Lab's Tina Mozelewski which ensured the validity of OpCost output. We also acknowledge and appreciate funding provided by the Joint Fire Sciences Program (Project # 13-1-03-8) and the Pacific Northwest Resource Monitoring and Assessment Program. Additional funding support was provided by the University of Idaho College of Natural Resources McIntire-Stennis project IDAZ-MS-0103 and the Idaho Forest Utilization Research (FUR) program.

English Equivalents

When you know:	Multiply by:	To get:
Acres	0.4046	Hectares
Cubic feet	0.0283	Cubic meters

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