Productivity and cost of marking activities for single-tree selection and thinning treatments in Arkansas

Tymur Sydor
Richard A. Kluender
Rodney L. Busby*
Matthew Pelkki

Abstract

An activity algorithm was developed for standard marking methods for natural pine stands in Arkansas. For the two types of marking methods examined, thinning (selection from below) and single-tree selection (selection from above), cycle time and cost models were developed. Basal area (BA) removed was the major influencing factor in both models. Marking method was significant in predicting the total time of the activity but not significant in estimating the cost per 10 ft.^{2}/acre of BA removed.

Tree marking is a vital and necessary part of forest operations during selective harvesting. During the marking procedure, trees to be harvested in the stand are selected according to harvest objectives and painted (marked). In the past, clearcut harvesting was predominant, and this diminished the need for thorough pre-harvest marking. However, recent increased emphasis on selective harvesting has made marking an important component of timber sale design. The increase of natural forest regeneration and non-timber utilization has forced managers to re-evaluate their harvesting strategies. The Land and Resource Management Plan for the Ouachita National Forest in Arkansas (ONF 2002) states the need to "emphasize the use of uneven-age management as the appropriate cutting method in areas adjacent to, or viewed from, highly sensitive areas or areas of high recreational use." While several authors (Hannah et al. 1981, Bell 1989, Kluender and Stokes 1994) have studied the productivity and cost efficiency of even- and uneven-age management and various harvesting techniques, pre-harvest timber marking activities have not been adequately addressed. Moser and Raney (1990) proposed a method to assure that field marking of trees conformed to the harvesting prescription. A calculator-assisted program compared a uniformly distributed random number for each tree in a stand to a cut probability, appropriate to the tree's diameter class. A tree was selected to harvest if the generated number was less than the cut probability. A similar procedure was used to generate cut-ratio marking guides in the study by Nowak (1997). Nowak combined crop-tree and area-wide marking guides in the SILVAH program to generate cut-ratio guides for hardwood forests in the Allegheny Plateau. Atrokhin et al. (1981) described a cost-saving marking procedure in a marking-overview paper. In this procedure, leave trees, not harvest trees, should be marked with paint. In the high intensity marking, the proportion of leave trees was lower than those to harvest, thus selecting and painting less trees reduced marking effort and cost.

Kluender and Stokes (1994) determined factors affecting productivity and costs of three harvesting methods. The object of their study was the harvesting operation, the next management step after marking. Kluender and Stokes showed that skidder time cycle was lowest for the clearcut method and highest for the single-tree selection method.

The authors are, respectively, Research Specialist, (currently doctorate student, Warnell School of Forest Resources, Univ. of Georgia, Athens, GA 30605; Professor, Univ. of Arkansas at Monticello, School of Forest Resources, Monticello, AR 71676; Research Forester, USDA Forest Serv., Southern Res. Sta., 701 Loyola Avenue, New Orleans, LA 70113; Associate Professor, Univ. of Arkansas at Monticello, School of Forest Resources. This paper was received for publication in September 2001. Article No. 9363.
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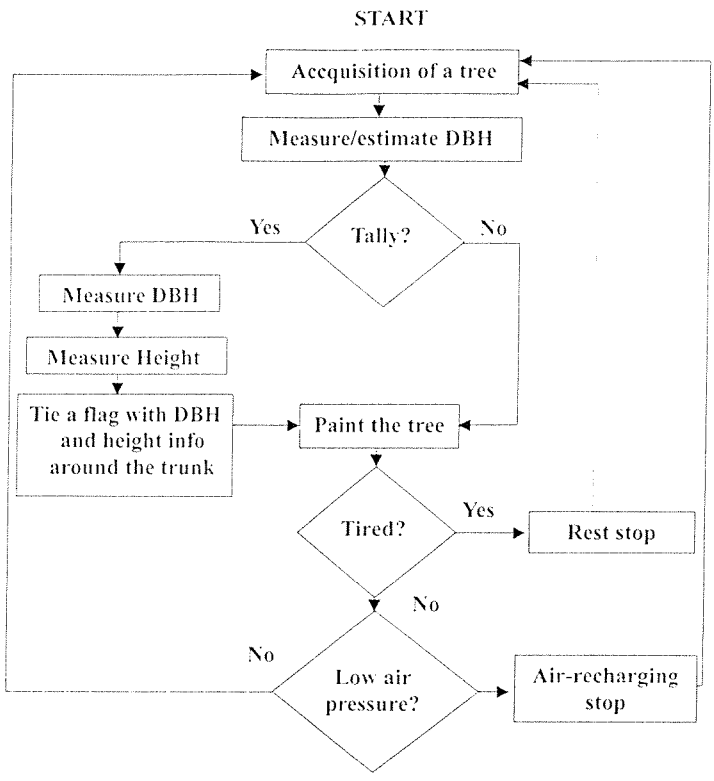

Figure 1. — Flow diagram of standard marking activity procedure.

Factors affecting felling productivity included the diameter at breast height (DBH) of harvested stems, intertree distance, and method of harvest. Costs of felling and skidding were highest on the single-tree selection stand and lowest on the clearcut stand. Harvest cost per hundred cubic feet of wood was inversely related to the harvest intensity and tree size (Kluender et al. 1998).

Methods

Study site

The study stands were located on the Fourche Ranger District, Ouachita National Forest, north of Hot Springs, Arkansas. The District has a full-time crew of workers (markers) whose major responsibility is marking of the forest stands for various harvesting prescriptions. All markers in the crew had at least 3 months of marking experience. The stands were composed primarily of shortleaf pine (*Pinus echinata* Mill.) and loblolly pine (*Pinus taeda* L.) with a small hardwood component (5% to 10%). Typically stands were located on the southern or southeastern aspect, although 2 out of a total 11 stands had a northern aspect. A stand for each marking method was divided into working units, which were the area tallied in 1 day.

Marking methods

The marking method reflects the silvicultural objective for a particular harvest prescription. Two methods were chosen to represent standard harvesting prescriptions. Single-tree selection and thinning from below (hereafter referred to as thinning) differ by the size of selected trees and the target basal area (BA). Thinning involves selection of trees with intermediate and suppressed crowns, typically with smaller diameter stems (selection from below). Single-tree selection, as practiced here, involves selecting trees with dominant and co-dominant crowns, typically with larger diameter stems (selection from above). Both methods are standard harvesting prescriptions on the Fourche. Flagging of stand boundaries and streamside management zones (SMZ) usually preceded marking in each harvesting stand. Marking was done on the basis of BA measured in square feet per acre ($ft.^2$/acre).

At Fourche, thinning was prescribed in mature stands with the intent of lowering BA to 70 to 90 $ft.^2$/acre and leaving a constant BA throughout the unit for better growth in the stand. Risk trees, pulpwood trees 5 to 9 inches DBH, and mature trees with DBH less than 18 inches were selected for harvest and painted (marked) on the trunk and stump with blue paint.

Single-tree selection was aimed at creating natural regeneration within a stand. Target BA was lowered to 60 to 80 $ft.^2$/acre throughout the stand with gaps and holes up to 0.25 acre in size, created as the place for natural regeneration. Trees of 18 inches and higher were selected for harvest along with pulpwood trees and marked with orange paint. Single-tree selection was used to achieve a "reverse-j" distribution of diameters, indicative of the uneven-aged stands.

Data

A marking cycle was counted as the time, in seconds, from the point when the marker has finished marking the previous tree to the point when he finished marking the current tree. Acquisition time was the time required to visually select the next marking tree and walk to it. DBH data were collected in 2-inch diameter classes. Data were collected by taking observations of a preliminary chosen marker. Markers were chosen for each day in alphabetical order of their names, with a different marker to be chosen each day. Harvesting selection was applied to the pine (loblolly or slash) species only; the hardwood component on the stand was not selected either as a main harvest species or as a pulp species. To the District, the difference between the two pine species was minimal, thus they were not noted in the selection.

Marking activity started with the marker walking up to the chosen tree to acquire it (**Fig. 1**). The tree's DBH was then measured or visually estimated to the 2-inch diameter class and called to the crew leader to be entered into a tally computer; then the tree was marked. Tally trees were proportionally selected among the marked trees with selection based upon a tree diameter for the estimation of the marked tree volume in the stand. For 10- to 14-inch DBH trees, every 200th marked tree was measured as a tally (0.5%). Trees in the 16-inch DBH class were tallied at a 1 percent rate, while 18-inch class trees were tallied at a 2 percent rate. Trees in the 20-inch or higher DBH class were tallied at a 10 percent rate. Pulpwood trees (DBH 5 to 9 inches) were tallied at a 10 percent rate.

Marked tree volume was calculated by DBH class for each stand separately.

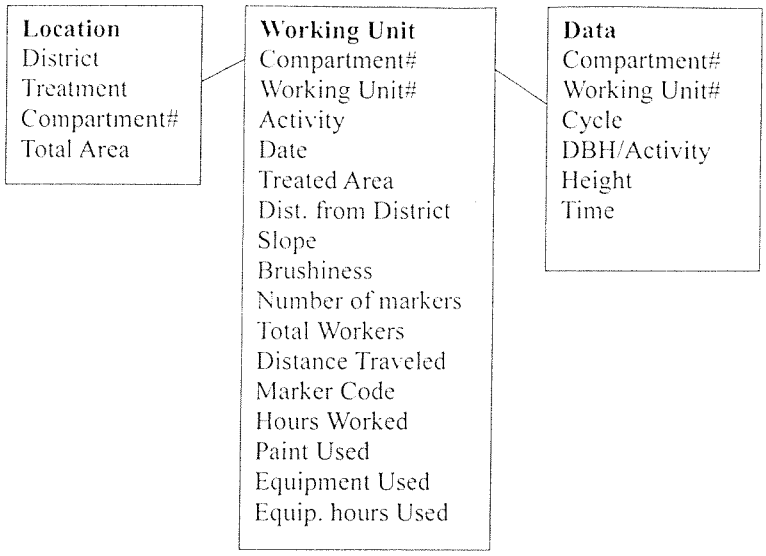

Figure 2. — Graphical representation of the database (containing three tables: Location, Working Unit, and Data) created to manage project data.

When the crew leader called a tree as a tally tree, its DBH was measured to a tenth of an inch with a diameter tape, and tree height was measured with an altimeter. Tally trees were flagged with DBH, height, and tally number written on the flag. Flagging the tally trees was a standard procedure at the District and was done for marking quality control purposes. After this, the marker moved to acquire the next tree. Tree height data were collected for tally trees only and therefore were not used in the analysis.

The whole crew took rest stops for 15 to 20 minutes, two to three times per day. Air recharging stops for the paint guns during the marking activity allowed for recharging the paint guns with air and additional short rest stops. These stops were taken by each individual crew member independently, and usually lasted no more than 3 minutes.

A working unit, part of a separate harvesting compartment tallied by markers on a particular day, represented each working day. The working unit size varied each day. The need to have working units arises from the fact that in a calendar day, a marking crew may undergo activities at two or more separate harvesting compartments with different prescriptions. The working unit data were composed of marker and working unit information.

Marker information contained data of the worker's total traveled distance at each working unit (measured with pedometer every day), amount of paint used by this worker (provided by markers), number of workers in the marking crew, and the code for the worker who was chosen for observation. Unit information contained acreage of the unit that was treated by the marking crew, the brushiness and average unit slope, and the distance from the District. Brush class index ranged from 1 (no brush) to 4 (heavy brush) and was determined visually for each working unit. Intermediate brush classes included 2 (light brush) and 3 (medium brush).

A Microsoft ACCESS database was created to manage and store the marking data. The graphical representation of the database is shown in **Figure 2**, which contains three tables. The Location table contains harvesting treatment, location, and size for each stand. In the Working Unit table, the general information about a particular working unit is collected. The Data table combines time cycle observations for each working unit.

During the 3-month period of February to April 2000, single-tree selection marking activities were completed on three stands, of which eight working units associated with tree marking were observed. Working units were 15 to 55 acres in size, depending on the hours worked and the size of the marking crew, with slopes ranging from 7 to 30 degrees. Thinning observations were collected in 6 stands divided into 21 working units. Thinning working units were 8 to 40 acres in size, depending on the number of hours worked and the size of the crew, and located on slopes ranging from 5 to 20 degrees. The amount of BA marked per acre was used as an indicator of marking intensity since it is an easily available parameter and is sensitive to both diameter and the number of trees.

Traversing and boundary layout represented an occasional activity done primarily in the large stands or stands adjacent to private property. For single-tree selection or thinning stands, boundary layout can be done along with the actual marking. Traversing and boundary layout prior to marking may be avoided in those stands where roads, ravines, or creeks form the natural boundary of the stand. Since only 2 working units out of 29 observed were engaged in pre-marking flagging and boundary layout, they were not included in the time or cost analysis.

Cost calculation of the marking activity consisted of the markers' labor cost, and the cost of machinery and equipment. Markers in the crew were of GS-6 grade, and the leader was a GS-7. Hourly salaries for GS-6 and GS-7 grades were taken from the 2001 General Schedule (U.S. Office of Personnel Management 2001), and were $11.72/hour and $13.03/hour for GS-6 and GS-7, respectively. Benefits that normally accompany these grade-level positions account for an extra $4.00/hour. Normal working conditions were assumed, with no overtime or weekend work. Similarly, GS-6 and GS-7 staffing levels were observed at each working unit.

Yearly maintenance of the transportation vehicle, with depreciation, accounted for $4,700 or $18/working day, and gas costs of $0.11/mile. Panama gun and Husky palm computer costs were assumed to depreciate completely in 5 years, with amortization costs at $0.04/hour and $0.33/hour, respectively. The cost of paint was estimated at $17.95/gallon from the Forestry Suppliers Inc. catalog (Forestry Suppliers Inc. 2000). Sensitivity analysis of the cost per 10 ft.^{2}/acre of BA was done with respect to annual increase in the markers salary and additional overtime (10 and 20%) work.

Results

Data

The average diameter of a marked thinning stand was much lower than that in single-tree selection (**Table 1**). This was not surprising since thinning was

Table 1. — Results of the study for two marking methods.

Factor	Marking method	
	Single-tree selection	Thinning
Working units	8	21
Number of observations (trees)	1,903	5,511
BA marked/acre[a] (ft.²/acre)	37.1	42.1
Mean DBH (in.)	14.2	11.9
Trees/10 ft.² of BA	2.61	4.25
Cycle time/tree (sec.)	50.94	36.40
Walking distance/acre (mi.)	0.12	0.17
Inter-tree distance (ft.)	68	54
Marking time/tree (sec.)	34.9	23.8

[a]Quadratic mean.

Table 2. — Statistical results for three models: estimation of time to mark, number of marked threes and estimation of marking cost per 10 ft.²/acre of BA removed (Eq. [1], [2], and [3], respectively).

Equation no.	Variable	Parameter estimate	t - value	p - value > |t|	F value of the model
2	Intercept	220.789	7.652	0.000	32.431
	A	-10.218	-3.159	0.004	
	B_m	1.057	2.931	0.070	
	ln B_m	-59.733	-5.091	0.000	
2	Intercept	- 406.279	-8.518	0.000	99.354
	A	100.875	9.699	0.000	
	Slope	2.1911	3.527	0.002	
	Ac_m	38.247	14.906	0.000	
	B_m	10.384	6.862	0.000	
	B_m^2	-0.050	- 2.820	0.011	
3	Intercept	37.5421	15.09	0.0001	43.78
	ln B_m	-9.9505	-12.93	0.0001	
	T_n	1.2603	6.20	0.0001	
	M	1.7372	4.19	0.0003	
	Ac	-0.3309	-7.89	0.0001	

essentially harvesting from below, while single-tree selection is harvesting from above.

BA marked in the single-tree selection stands ranged from 17.6 to 54.4 ft.²/acre and in thinning stands from 10.4 to 64.6 ft.²/acre. Average thinning marking intensity was higher than in single-tree selection (42.1 and 37.1 ft.²/acre, respectively) (**Table 1**). This occurred because a larger quantity of smaller diameter trees was marked to obtain 10 ft.² of BA removed for thinning than for single-tree selection. The fact that fewer trees were needed to satisfy the requirements of the BA in single-tree selection created larger travel distance between marked trees, thus increasing marking cycle time (**Table 1**). Also, a high proportion of large-diameter trees in the single-tree selection marking method increased the number of tallied trees because the proportion of tally trees for higher diameters was larger than for smaller diameter trees. The larger number of tally trees increased the mean marking time per tree, since marginal marking time for tally tree is greater than marginal marking time for non-tally tree. Mean marking time per tree and mean cycle time were higher for single-tree selection, 34.9 and 50.9 seconds, respectively.

Cycle time

To estimate the time needed for the marking activity, two equations were developed with SYSTAT software (SPSS 1999) using generalized least squares procedure (GLS). Both equations were estimated with a stepwise linear regression technique and 10 percent cut-off value for parameter estimate significance. The first equation modeled an average total marking time per tree, in seconds (Eq. [1]). This was a total marking cycle estimate and included acquisition and tallying time, and rest and air-recharging stops. Mean marked diameter of working unit and two indicators of marking site condition (slope and brushiness) were initially included in the model, but were removed because they were found to be insignificant. The remaining variables, a dummy variable for marking activity and marked BA per acre, exhibited no significant correlation. One outlier was deleted from the dataset due to the high value of the studentized residual, which reduced the sample size to 28 observations.

Equation [2] estimated the number of marked trees per marker using the following independent variables significant at $\alpha = 0.10$: marking activity (dummy), slope, marking area per marker, and BA marked per acre. As in the previous equation, these variables showed no significant correlation among them. Two outliers and one highly leveraged observation were deleted and the sample size for Equation [2] was reduced to 26 observations.

$$T_t = 220.79 - 10.22 * A + 1.057 * B_m - 59.73 * \ln B_m \quad [1]$$

$$n = 28$$

$$r^2 = 0.802$$

$$T_m = -406.28 + 100.88 * A + 2.19 * S + 38.25 * Ac_m + 10.38 * B_m - 0.05 * B_m^2 \quad [2]$$

$$n = 26$$

$$r^2 = 0.961$$

where:

T_t = average total marking time per tree (sec.)

T_m = number of marked trees per marker

A = dummy variable for marking activity (0 = single tree selection, 1 = thinning)

B_m = BA marked per acre (ft.²/acre)

S = estimate of the site slope (degrees)

Ac_m = marking area per marker (acres)

Statistical results for Equations [1] and [2] are summarized in the text following each equation and in **Table 2**.

Table 2 indicates that the individual parameters and model construction are statistically significant. High coefficients of determination (r^2) for each equation indicate that the independent variables account for a large percentage of the observed variation in the dependent variables of both equations. The type of marking activity and BA marked were one of the most important factors affecting marking productivity, which corresponded to the DBH and intertree distance factors from the study by Kluender and Stokes (1994). During single-tree selection, markers spend on average 10.2 seconds longer per tree than in thinning activity. Larger diameter trees in single-tree selection were more dispersed throughout the working unit, thus requiring longer walking and thus, longer tree selection times. Walking distance per acre in thinning was greater than that for single-tree selection, hence rest stops were more frequent in thinning (**Table 1**). Consequently, air-recharging and rest stops tend to increase average marking time per tree in thinning.

The objective of thinning (selection from below) was to select trees with smaller crowns (diameter). On average, 101 more trees per acre were marked in thinning than in single-tree selection. Smaller diameter trees were growing on steeper slopes: a parameter estimate for this variable indicated that 22 more trees would be marked per 10 percent increase in the slope of the working unit, if all other factors were held constant.

Cost per acre

A linear equation (Eq. [3]) was developed using a stepwise linear regression technique to estimate the unit cost of marking activities. Independent variables significant at the $p = 0.10$ significance level included BA marked per acre, net marking time, number of markers, and acres marked. Such variables as slope, brushiness, and a dummy variable for marking activity were initially included in the model but they did not pass the significance level test and the slope variable showed a significant correlation with a variable for the marking time spent on the site.

$$C = 37.54211 - 9.9505 * \ln B_m + 1.2603 * T_n + 1.7372 * M - 0.3309 * Ac \quad [3]$$

$$n = 29$$

$$r^2 = 0.88$$

where:

C = marking cost ($) per 10 ft.^{2}/acre of BA removed

$\ln B_m$ = natural logarithm of BA marked per acre (ft.^{2}/acre)

Ac = number of acres to mark (acres)

M = marking crew size (less the leader)

T_n = marking time spent on site (hr.)

Marking time spent on the site in hours was obtained from the results of calculation of average total marking time per tree and the number of marked trees per working unit (Eqs. [1] and [2]). The results of the two equations were multiplied and then divided by 3600 to transform the marking time estimate from seconds to hours. The statistical details of the cost equation are presented in **Table 2**.

BA marked and the numbers of markers in the crew were major factors affecting the marking cost per 10 ft.^{2}/acre of BA removed (Eq. [3]). It was not surprising that the marking of a larger portion of BA per acre was more cost efficient than marking a small portion of the BA in a stand. Marking cost per 10 ft.^{2}/acre of BA removed was inversely related to the marking intensity, represented by the BA marked, which supported the conclusions of Kluender et al. (1998).

Larger marking crews were less cost efficient than smaller ones, although the possibility of a crew larger than four markers was not investigated. An additional marker in the crew would increase the unit cost of marking 10 ft.^{2} per acre by $1.74. We can also speculate that crews larger than four markers will generally increase the cost of marking. There are several explanations for this. First, additional markers in the crew would require an additional transportation vehicle, since the current vehicle, a Chevrolet Suburban, could seat a maximum of five people with gear. Also, additional markers would create difficulty for the crew leader when inputting marking data into the palm computer and thus force, at some point, the addition of a new input data worker. This

Table 3. — An algorithm for marking cost estimation.

Step no.	Estimates	What to do	Needed data/remarks
1	Number of trees to mark per marker (T_m)	$T_m = -406.28 + 100.88 * A + 2.19 * S + 38.25 * Ac_m + 10.38 * B_m - 0.05 * B_m^2$	$A = 0$ for single-tree selection; 1 for thinning S = slope of a stand (degrees) Ac_m = marking area per marker (acres) B_m = BA to remove (ft.^{2}/acre)
2	Average time per tree (T_t) (sec.)	$T_t = 220.79 - 10.22 * A + 1.057 * B_m - 59.73 * \ln B_m$	Same as above
3	Net marking time (T'_n) (sec.)	$T'_n = T_t * T_m$	
4	Net marking time (T_n) (hr.)	$T_n = T'_n / 3600$	Marking time spent on site (hr.)
5	Cost of marking activity per 10 ft.^{2}/acre of BA removed (C) ($)	$C = 37.54211 - 9.95 * \ln B_m + 1.2603 * T_n + 1.74372 * M - 0.3309 * Ac$	$\ln B_m$ = natural logarithm of the BA to remove (ft.^{2}/acre) T_n = net marking time (hr.) M = number of markers in a crew Ac = number of acres to mark (acres)

Table 4. — Elasticity of the marking cost to salary increases and overtime work.

Factor	Percent change in average cost of marking per acre per 10 ft.²/acre of BA removed in response to factors	
	Single-tree selection	Thinning
	(%)	
2.7% basic rate salary increase (for year 2002)	+ 1.6	+ 1.4
10% overtime	+ 2.9	+ 2.8
20% overtime	+ 5.7	+ 5.4

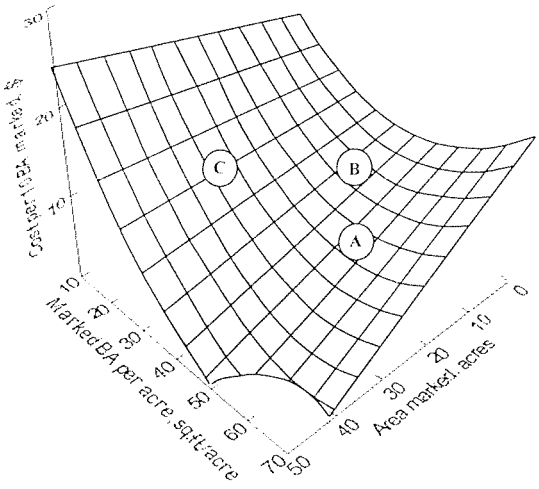

Figure 3. — Cost surface as a function of BA and acreage with tree regions (A = high marking intensity; B = average marking intensity; and C = low marking intensity) showing the concentration of data points for two methods.

would decrease productivity and increase operational costs. In the stands with a low BA marked, or small acreage, a large working crew would be a burden.

The results of Equations [1], [2] and [3] are summarized in **Table 3**. The net marking time can be calculated from Equations [1] and [2]. Results of the two equations were to be multiplied to calculate the net marking time on the site, in seconds. The multiplication result was then divided by 3600 to obtain net marking time in hours. To estimate the total marking time, driving time from the District to the working unit has to be added to the net marking time.The marking cost model (Eq. [3]) combines estimated marking time on the site in hours along with the natural logarithm of marked BA, the size of the marking crew, and the size of the working unit and estimates the cost of marking 10 ft.²/acre of BA removed.

Results of sensitivity analysis of the marking cost per 10 ft.²/acre of BA removed with respect to the annual increase in the markers' salary due to inflation and overtime work is shown in **Table 4**. An annual 2.7 percent increase in the marker's salary would increase the cost of marking per 10 ft.²/acre of BA removed by 1.6 percent for single-tree selection and 1.4 percent for thinning. In the case of emergency, when overtime work was needed to finish marking, the total marking cost would increase by 2.8 to 2.9 percent for each 10 percent increase in overtime hours.

Three regions marked on **Figure 3** represent the typical data clusters of a marking operation and show the complicated structure of the marking cost surface. Region A was typical of both thinning and single-tree selection operations. It combined high marking intensity with average size of the stand (30 to 35 acres). Marking cost of the high-intensity region A (45 to 50 ft.²/acre) would increase with decreasing marking stand size. This suggests that stands where a large portion of BA would be removed should be marked in large working units to decrease cost per 10 ft.²/acre of BA removed. Region B was comprised of small stands (20 to 25 acres) with an average marking intensity (42.1 ft.²/acre). This region was typical of stands in the study that were marked for thinning. Thinning stands of average marking intensity might be marked in small as well as large working units, since the size of the working unit should not appreciably affect marking cost per 10 ft.²/acre of BA removed. For single-tree selection stands (region C) with low marking intensity (25 to 30 ft.²/acre), operating in small stands would slightly lower the marking cost per 10 ft.²/acre of BA removed. In general, when operating working unit size increases, accompanied by a high marking intensity, marking cost per 10 ft.²/acre of BA removed decreases. Marking intensity of 30 to 35 ft.²/acre was observed to be the most efficient for any harvesting prescription.

Conclusions

Numerous factors affect marking productivity. Although stand characteristics are impossible to control, these models can help estimate their impacts on time and cost of marking activities. The amount of BA marked per acre was the single most important factor affecting marking cycle time of both treatments: single-tree selection and thinning. As the BA marked per acre increased, the time of the marking cycle decreased. It took more time to mark the same BA for thinning selection than for single-tree selection. This was a reflection of the fact that the mean tree diameter marked in thinning was smaller and distance traveled per acre was larger, thus requiring more frequent air-recharging and rest stops. A larger amount of stops increases the marking cycle time per tree. The time spent putting the paint on the tree was not affected by its size, which was why the value of average marked diameter was not significant in the model, but BA marked per acre was a major productivity factor. The marking method and objective significantly affected marking time. Single-tree selection marking stands produced 101 fewer trees per acre for the same BA of thinning treatment. Trees of smaller diameters were located on higher slopes, thus slope increase would increase the number of marked trees for the same marked BA level.

Treatment method, thinning or single-tree selection, did not affect the cost per 10 ft.²/acre of BA removed. Increased crew size resulted in a higher cost per 10 ft.² of marked BA, although a crew of

more than four markers was not observed. A crew size of three to four markers and one data input worker was considered optimal for any marking activity. Larger BA marked per acre decreased the cost per unit (10 ft.^{2}/acre of BA removed) of BA.

This study created models for marking time estimation of two standard marking methods in natural pine stands in Arkansas. The information needed prior to marking is BA to be removed per acre, the size of the stand, and the slope of the stand. In general, this information is readily available in advance of the marking activity. The estimated marking time, along with number of markers in the crew, BA per acre, and the size of the stand, can then be used to calculate the cost per acre of marking 10 ft.^{2}/acre of BA (**Table 3**). The two estimates, marking time and marking cost, allow for more precise advance planning of time and cost budgets. Advance planning brings efficiency of time and resource distribution and, thus, improves forest management.

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