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# PRODUCTION AND COST ANALYSIS OF A FELLER-BUNCHER IN CENTRAL APPALACHIAN HARDWOOD FOREST

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ABSTRACT - A time study was conducted to evaluate the productivity and cost of a feller-buncher operating in a Central Appalachian hardwood forest. The sites harvested during observation consisted of primarily red maple and black cherry. Trees felled in the study had an average diameter at breast height (DBH) of 16.1 in. and a total merchantable height of 16 ft. A Timbco 445C Hydro-buncher was used in conjunction with manual topping and delimbing with a Husqvarna 55 chain saw. Hourly productivity ranged from 428.9 to 2267.7 ft3 per productive machine hour (PMH) for the feller-buncher and 178 to 2186 ft3/PMH for the top/delimber. Hourly costs were estimated to be $99.68/PMH for the feller-buncher and $28.23/PMH for the top/delimber. Estimated average costs of$0.08/ft3 for the feller-buncher and $0.04/ft3 for the top/delimber were derived, based on these production estimates.

## INTRODUCTION

Manual felling with a chainsaw is most commonly used in the Appalachian hardwood region, but the need for increased production and safety has encouraged some companies to look at mechanized alternatives such as fellerbunchers. In the south, harvesting operations have moved quickly to complete mechanization with highly productive equipment in the past 25 years (McDonald et aI., 2000). As a result of that trend, sawhead feller-bunchers have become standard equipment on many Southern harvesting operations (Greene and McNeel, 1991). Being relatively new to the hardwood region, little if any research has been conducted to examine the production and cost effectiveness of the feller-buncher when used on the terrain and with tree species common to this region.

It has been shown that harvest system mechanization leads to higher levels of productivity in the system.. A drawback is that as mechanization increases, costs also increase (Blinn et aI., 1986). Site conditions are also a problem when using mechanized systems. Feller-bunchers can work on relatively steep slopes, but it is not known how cost effective they are in those conditions. Characteristics of the tree species in this region may also be a problem. Feller bunchers are commonly used for cutting coniferous species, since these species are typically characterized by straight boles and relatively small branches. In the Central Appalachian region mechanized systems would be required to deal with trees that might be leaning and with crown weights that are excessive. This makes for placement of trees after cutting and travel while carrying trees difficult, especially on steep slopes.

Time studies have been a popular way of investigating productivity of feller-bunchers and other machines on logging operations (Wang and HaarIaa, 2002). The objective of this study is to examine the production/cost effectiveness of using a feller-buncher in the Central Appalachian Hardwood Region. Results can help loggers and logging managers compare this machine to others and choose an appropriate one to improve the operations in the regIOn.

## METHODS

An elemental time study was conducted on logging operations in Northern West Virginia. The field study was conducted from February to April 2002 on two sites. Both sites contained most hardwood species common to the Appalachian region but were predominantly made up of 5 major species: red maple *(Acer rubrum),* black cherry *(Prunus seratina),* yellow poplar *(Liriodendron tulipifera),* black locust *(Robina pseudoacacia),* and white ash *(Fraxinus Americana).* All other species were grouped together as "Other hardwoods". Average DBH of the trees harvested was 16.1 inches and ranged from 7 and 31 inches. Slope on the sites ranges from 0 to 30% with an average of 15%. The machine used in the study was a Timbco 445C Hydro-buncher. This machine has a 260 hp engine, is capable of 4-way cab leveling, and has a boom reach of 167 inches. Top/delimbing was done using Husqvarna 55 chain saws, which have a 3.4 hp engine.

A handheld computer loaded with the Windows CE based Time Study Data Logger was used to measure and record elemental times (Wang et aI., 2001). When the handheld computer could not be used, times were measured using a stopwatch and recorded on paper. A work cycle consisted of the following elemental functions:

*Drive to tree:* Starts when the feller-buncher finishes the previous cycle and begins moving to the next tree to be cut. Ends when movement has stopped and felling is ready to begin.

*Cut tree:* Begins when the head is positioned on the tree and ends when the tree is completely severed from the stump.

*Drive to Dump:* Begins when the feller-buncher moves from the stump with the tree and ends when movement is stopped and dump is started.

*Dump tree:* Begins when tree is tilted by head into dump position and ends when tree hits the ground

*Bunch:* Begins after tree is dumped and continues until move to next tree starts

Harvesting factors recorded for the feller buncher were distance to tree, distance to dump, tree species, DBH, and merchantable height. Only one tree was cut per cycle, so the number of trees per cycle was not a factor. Order and location of felled trees was noted so that species, DBH, and merchantable height of the trees could be recorded when felling was complete. DBH for each harvested tree was measured to the nearest inch but was later classed as follows for simplification of data analysis: (7 to 10 in.) ~ 10 in.; (11 to 15 in.) => 15 in.; (16 to 20 in.) => 20 in.; (21 to 25 in.) => 25 in.; (26 to 31 in.) => 30 in. Merchantable height of each felled tree was measured to the nearest Yz log or 8 feet. Due to the small number of occurrences of logs over 32 feet, all logs over 32 feet were classed as 32 feet to simplify analysis. After felling was complete on the group of trees being observed, the felled trees would be topped/delimbed. This operation required from one to three workers at a time, but usually consisted of two workers. Because of the difficulty in collecting topping and delimbing times for individual trees for each worker, total toppingldelimbing time was measured for groups of trees and an average time per tree was calculated.

## ANALYSIS

A total of 500 felling and topping/delimbing cycles were collected in order to provide a statistically viable dataset. An Analysis of Variance (ANOV A) model was performed on the dataset to determine if any differences existed between elemental times, cycle time, and hourly productivity. The model is expressed as:

$$T_{ijkl} = \mu + S_j + DBH_i + L_k + \varepsilon_{ijkl}$$
$$i = I, 2.., 6$$
$$j = 1,2,...,5$$
$$k = 1,2,3,4$$
$$l = 1,2,..., n$$

where *Tijk/* represents the f1' observation of the elemental times, cycle times, and hourly production for the jtt1 species, lh DBH class, and kth height class; ~ is the mean of each response variable; Sj is the effect of the *z-th* species; *DB~* is the effect of the *J.fu* DBH class; *Lk* is the effect of the kth height class; *tijkl* is an error component that represents uncontrolled variability; and *n* is the number of observations within each treatment. Regression techniques were used to produce prediction equations for elemental times, hourly productivity, and unit cost.

## RESULTS

Means and significant levels of statistics for the fellerbuncher and toppingldelimbing during the time and motion study were computed (Table I). Calculations were done by species, DBH (in), and merchantable length oflog cut (ft).

## ELEMENTAL TIMES

*Total felling time* - Adding all productive elements of felling including drive to tree, cut, drive to dump, dump, and bunch for each tree gives us a total felling time for each individual tree. Mean total felling time differed significantly among species (F=13.21; df = 5, 486; P = .0001), DBH (F=12.69; df= 4,486; P = .0001), and height (F= 23.32; df= 4,486; P = .0001) with ranges of.85 to 1.46 minutes, .79 to 1.85 minutes, and .89 to 1.78 minutes respectively (Table I). A regression model was developed to estimate total felling time per tree (Table 2). Total felling time was best described by DBH and merchantable height of the tree being felled, distance to tree, and distance to dump.

*Drive to tree* - The density of the stand as well as the intensity of the harvest affect time moving to the tree to be cut because thinnings leave trees that must be maneuvered around. Drive to tree was the largest of the elemental times measured. There were significant differences in drive to tree time among species (F=5.09; df = 5, 486; P = .0001) with a range of .45 to .86 minutes and among height (F= 10.94; df = 4, 486; P = .0001) with a range of .49 to 1.07 minutes. Mean drive to tree time ranged from .44 to .70 minutes among DBH classes and showed no significant difference (F=1.3I; df = 4, 486; P = .2664) (Table I).

*Table* 1. - Means and significance levels of statistics for the felling and top/delimbing during time and motion studies.'

| | Elemental Times (min) | | | | | | | | | Production Estimates (ft'IPMH) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total Felling Time | Drive to Tree | Cut | Drive to Dumn | Dump | Bunch | Feller -Buncher Delav | Top! Delimb | T opIDelimb Delav | Felling Productivity | . ToplDelimb Productivity |
| Species | | | | | | | | | | | |
| Red Maple | 1.06 A | 0.5IAB | 0.17A | 0.03A | 0.10A | 0.25 A | 0.35 A | 1.53 A | 0.31 A | 1204 A | 723 A |
| Black Cherry | 0.85 A | 0.45B | 0.15A | 0.04A | 0.12A | 0.I0B | 0.00 A | 1.61 A | 0.06 A | 1386.1 AB | 660.5 B |
| Yellow Poplar | 1.46B | 0.86C | 0.21 B | 0.09B | 0.10A | 0.20 AD | 0.91 A | 1.79 B | 0.20 A | 1478.7 B | 989.7 C |
| Black Locust | 0.90 A | 0.5IAB | 0.10C | 0.02A | 0.11 A | 0.I7BD | 0.85 A | 1.55 A | 0.10 A | 939.8 C | 400.3D |
| White Ash | 1.06 A | 0.62 AB | 0.10C | 0.08B | 0.09A | 0.16BD | 0.00 A | 1.56 A | 0.44 A | 1162.1 AC | 511.8E |
| Other | 1.39B | 0.70 BC | 0.22B | 0.02A | 0.10A | 0.36 E | 0.41 A | 1.69AB | 0.18 A | 1297.3 AB | 920.8 F |
| DBH (in) | | | | | | | | | | | |
| 10 | 0.79 G | 0.44 G | 0.07 G | 0.02 G | 0.08 G | 0.17 G | 0.50 G | 1.50 G | 0.00 G | 428.9 G | 178 G |
| 15 | 0.99 GH | 0.54 G | 0.10G | 0.05G | 0.12H | 0.18G | 0.11G | 1.52G | 0.20G | 878.8 H | 4l4H |
| 20 | 1.15 HI | 0.61G | 0.I7H | 0.04G | 0.I0GH | 0.23G | 0.50G | 1.68GH | 0.22G | 1437.71 | 7861 |
| 25 | 1.281 | 0.65G | 0.29 I | 0.03G | 0.11 G | 0.20 G | 0.94G | 1.76H | 0.30G | 2333.6 J | 1517 J |
| 30 | 1.85 J | 0.70G | 0.61 J | 0.00G | 0.08H | 0.46 H | 0.00G | 1.78H | 0.00G | 2267.7 J | 2186K |
| Length (ft) | | | | | | | | | | | |
| 8 | 0.89L | 0.49 L | 0.10L | 0.03L | 0.11 L | 0.15L | 0.23 L | 1.46L | 0.16L | 638.4 L | 326L |
| 16 | I.04LM | 0.55L | 0.14L | 0.04L | 0.10LM | 0.21LM | 0.45L | 1.59 M | 0.24 L | l180.1M | 596M |
| 24 | 1.18M | 0.52L | 0.26M | 0.05L | 0.11 L | 0.25 L | 0.04L | 1.71M | 0.09L | 1910.1 N | I184N |
| 32 | 1.78N | 1.07M | 0.32 N | 0.03L | 0.09M | 0.27L | 1.06L | 1.95N | 0.19L | 2238.6 0 | 17100 |

a Means with the same capital letter in a column are not significantly different at the 5 percent level with Duncan's Multiple-Range Test.

*Cut* - Time to cut each tree was significantly different among species (F=I1.68; df = 5, 486; P = .0001) ranging from.1O to .22minutes, DBH (F=119.90; df= 4, 486; P = .0001) ranging from .07 to .61 minutes, and height (F= 64.58; df = 4, 486; P = .0001) ranging from .10 to .32 minutes (Table 1). A model developed using regression analysis allows estimation of cut time per tree (Table 2). It was found that cut time was affected by DBH and merchantable height of the tree.

*Drive to dump* - Drive to dump was not always performed in the felling cycle so it accounts for much less of total felling time than drive to tree. There were significant differences in drive to dump times for species (F= 3.84; df= 5, 486; P = .0020) with times ranging from .02 to .09 minutes. No significant differences were found among DBH classes (F=1.34; df = 4, 486; P = .2558) with times ranging from 0 to .05 minutes or among height (F= .23; df= 4, 486; P = .8770) with a range of .03 to .05 minutes. (Table 1).

*Dump* - Dump time was found to be significantly affected by DBH (F=5.05; df = 4, 486; P = .0005) ranging from .08 to .12 minutes. No significant difference was found for dump time among height (F=1.99; df = 4, 486; P = .1144) ranging from .09 to .11 minutes or species (F= 1.50; df = 5, 486; P = .1868) ranging from .09 to .12 minutes (Table 1).

*Bunch* - Bunch time was found to significantly differ among species (F=16.42; df = 5, 486; P = .0001) ranging from .10 to .36 minutes, DBH (F=7.88; df = 4, 486;. P = .0001) ranging from .17 to.46 minutes, and height (F= 4.78; df = 4, 486; P = .0027) ranging from .15 to .27 minutes (Table 1).

*Feller-buncher delay* - Feller buncher delay was only observed 20 times during the study. Delay was usually due to maintenance of the saw and included replacing the chain when dull and the bar when bent. Some delay due to hydraulic line failure also occurred. Delay of the fellerbuncher was not significantly different by species (F=1.04; df = 5, 486; P = .3947), DBH (F= 1.00; df = 4, 486; P = .4091), or height (F= .93; df = 4, 486; P = .4475) with ranges of 0 to .91 minutes, 0 to .94 minutes, and .04 to 1.06 minutes respectively (Table 1).

*Top/delimb* - Top/delimb time was found to significantly differ by species (F=4.26; df = 5, 486; P = .0008), DBH (F=6.97; df= 4, 486; P = .0001), and height (F= 15.88; df= 4, 486; P = .0001) with times ranging from 1.53 to 1.79 Ininutes, 1.50 to 1.78 minutes, and 1.46 to 1.95 minutes respectively. (Table 1).

*Top/delimb delay* - Only 20 observations of delay were observed for top/delimbing. The main delay was chain sharpening and refueling. Top/delimb delay was found not to be significantly different by species (F= .96; df = 5, 486; P = .4422), DBH (F= .69; df = 4, 486; P = .5989), or height (F= .45; df= 4, 486; P = .7149) with times ranging from .06 to .44 minutes, 0 to .30 minutes, and .09 to .24 minutes respectively (Table 1).

Table 2. Models to estimate times and productivities.

| | Models [a] | $R^2$ | RMSE | P-value |
|---|---|---|---|---|
| Cut Time per tree (min) | $0.24-0.04DBH+0.007Length+0.0005DBH*L+0.0015DBH^2-0.00035L^2$ | 0.46 | 0.13 | 0.0001 |
| Total felling time per tree | $0.367+0.0008DBH^2+0.00026L^2+0.02246\ DistT+0.00679DistD$ | 0.61 | 0.45 | 0.0001 |
| Feller-buncher productivity (ft 3/PMH) | $417.96+5.72DBH*L-1.44*L^2-17.77$Distance to tree | 0.55 | 685.9 | 0.0001 |
| Top/Delimb productivity (ft $^3$/PMH) | $365.95-56.19DBH-14.39L+3.8lDBH*L+2.22DBH^2-0.63L^2$ | 0.83 | 248.36 | 0.0001 |

[a]DBH = diameter at breast height (in); L = merchantable length (ft); DistT = Distance to tree (ft); DistD = Distance to dump (ft);
RMSE = root of mean square error

PRODUCTIVITY AND COST

*Felling Productivity* - Productivity of the feller-buncher was significantly different among species (F=5.22; df= 5, 486; P = .0001), DBH (F=87.91; df = 4, 486; P = .0001), and height (F= 89.35; df = 4, 486; P = .0001) with ranges of 939.8 to 1478.7 ft3/pMH, 428.9 to 2333.6 $ft^3$/pMH, and 638.4 to 2238.6 $ft^3$/pMH respectively (Table 1). A regression model was developed to estimate the productivity of the feller-buncher (Table 2). Factors that affect felling productivity are DBH, merchantable height, and distance between harvested trees.

*Top/De/imb Productivity* - Productivity of the top/delimber was significantly different among species, DBH, and height ranging from 400.3 to 989.7 $ft^3$/pMH, 178 to 2186 ft3/pMH, and 326 to 1710 $ft^3$/pMH respectively (Table I). A regression model was also developed to estimate the productivity of the top/delimber (Table 2).

Estimates of costs were done using the machine rate method (Miyata, 1980). The feller-buncher was purchased for \$225,000 in 1998 and was in used condition with 2300 hours from the previous owner. After an anticipated economic life of 4 years, salvage value would be \$45,000. Interest, insurance, and taxes were assumed to be 14% of the purchase price. Maintenance was estimated at 50% of depreciation. Operator cost was assumed to be \$10/hr with fringe benefits of 35%. Fixed costs were calculated to be \$51.58/PMH and operating cost were calculated at \$27.33/PMH. Total cost was estimated to be \$99.68/PMH. The chainsaw used to top/delimb costs \$300 and has an economic life of 6 months, after which time there is no salvage value. Total cost was estimated to be \$28.23/PMH. An average productivity of 1266.6 $ft^3$/pMH for felling and 726.3 $ft^3$/pMH for top/delimbing allowed an estimated average cost per volume of \$0.08/$ft^3$ for the feller-buncher and \$0.04/ft3 for the top/delimber.

CONCLUSION

Total felling time was most affected by distance between harvested trees and significantly differed from .79 to 1.85 minutes among DBH classes. This can be explained by the fact that drive to tree was a major part of the work cycle making up nearly half of the average work cycle. Cut time per tree was most affected by DBH and was significantly different among DBH classes with a range from .07 to .61 minutes. Productivity of the feller-buncher was most affected by and differed significantly among merchantable height with a range from 638.4 to 2238.6 $ft^3$fPMH. Top/delimber productivity was most affected by and significantly differed among DBH classes and merchantable height with ranges of 178 to 2186 $ft^3$/PMH among DBH classes and 326 to 1710 ft3/PMH among heights. Among species, yellow poplar yielded the highest productivity with 1478.7 $ft^3$/PMH for felling and 989.7 $ft^3$/PMH for top/delimbing. This was probably due to its large size and straight boles compared to other hardwoods.

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