PRODUCTIVITY AND COST ANALYSIS OF FELLER BUNCHER AT SAO HILL FOREST PLANTATIONS, TANZANIA

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ABSTRACT

Timber harvesting operations in Tanzania are changing from semi-mechanized and labour intensive methods to fully mechanized operations. To be cost effective, such operations must be carefully planned and controlled. This requires detailed information on every aspect of timber harvesting machines. This study was therefore designed to analyze the productivity and costs of using feller bunchers for timber harvesting at Sao Hill Forest Plantations. Productivity studies were performed during clear felling operations. Continuous time study technique using snap-back timing method was used for data collection on productive and delay times. Supplementary cost data was obtained from records at the logging department of Mufindi Paper Mill Company. Data were analyzed using Microsoft Excel spreadsheet to determine productivity and costs as a function of stand variables and terrain factors. Results showed that, the feller buncher production rates ranged from 16.5m^3/h to 80 m^3/h when the tree sizes (Dbh) varied from 11cm to 32cm respectively. Further results showed that productivity and costs were highly affected by the moving distances of the feller buncher from a tree to tree. Overall, the distance and the tree size had significant influence on the productivity and costs the feller buncher. The unit felling cost for feller buncher averaged 2,075 TZS/ m^3. The study concludes that, the higher initial capital investment of feller buncher felling could be paid off by higher hourly production.

Key words: Timber harvesting, labour, semi-mechanization, Tanzania.

INTRODUCTION

Harvesting of plantation timber from thinning and clear-cuts in Tanzania started in various locations country wide since 1970s (Ahlback1986). .Logging operations were done by the government through Logging and Road Building Project (LRBP) agency under the Forest and Beekeeping Division (FBD). During that period the government also owned most of the wood processing industries. According to Dykstra (1983), most of the felling operations were labour-intensive and semi- mechanized. Cutting was done by axes, two-man crosscut saws and chainsaws (Mshimbula 1996). However, due to the structural adjustment programme where the government detached itself from doing business, most of the wood industries were sold to private companies through privatization (Ngaga 1998) which wadaimed at improving production, safety, quality and to reduce operational costs. As a result, some of the privatized companies, including Mufindi Paper Mill, revolved their operations. Mufindi Paper Mill, which isone of the giant forest based industries that logged and processed wood from Sao Hill forests, introduced feller buncher for tree felling and bunching. A feller-buncher cuts trees using hydraulic powered cutting heads with chainsaw, circular saws or shears. Then, it lifts the entire tree and accumulate into bunch using its hydraulic arms. The trees are then transported full-length by a skidder to the landing for further transportation to the mill (Abdullah *et al*. 2006).

Studies have shown that the production levels and cost of using of feller buncher varies depending on several variables including forest stand, stand density, site and operational factors, ground conditions (slope, ground roughness, soils), tree size, extraction distance, machine designs, operator skills and motivation (Kellogg and Spong 2004). However, the key variables that affect the performance of a feller-buncher in Tanzania conditions have neither been identified nor studied. Therefore this study evaluated the performance of feller buncher at Sao Hill forest plantation (SHFP) in order to identify the key variables that determine feller buncher productivity and cost. Specifically the study aimed to: (1) determine productivity and cost of feller buncher, (2) determine the factors affecting productivity and cost of feller buncher. The results of this study will contribute to improved logging operation by using this machine in Tanzania plantation forests.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Sao hill forest plantation in a clear felling operation which was performed by Mufindi Paper Mill Company Ltd. Sao-Hill is the largest plantation forest in Tanzania with 43 000 ha of planted forests out of total gazetted area of 95 000 ha (Sumari 2008)**.** Sao-Hill is found in Iringa Region. It is located between latitude 8°18’S to 8°33’S and longitude 35° 06’- 35° 20’ E, in the southern highlands of the country. This forest supplies round woods to Sao Hill Sawmills Limited and Mufindi Paper Mill Company Limited as the two giant industries. It is also the source of raw materials for about 140 small sawmills and two transmission poles treatment plants. For managerial convenience SHFP is divided into four divisions namely Ihundi, Ihefu, Ihalimba and Mgololo each with a divisional manager reporting to the plantation manager. The main tree species planted are *Pinuspatula, P. eliotii, P. caribea, P. cassia, Eucalyptus saligna, E. maidenii, E. grandis* and *Cupressus lusitanica.*

The climate of Sao hill forest plantations is characterized with rainy season from November through May and a dry season during the rest of the year. The area receives between 600 mm to 1 300 mm of rainfall annually (Mlowe 2007). Temperatures are fairly cool, reaching close to freezing point between June and August. The mean monthly minimum and maximum temperatures are 10 °C and 23 °C respectively.

The soils are mainly drystric nitsols in association with orthic cresols (Nykvist 1976; Ngegba 1998). These are sandy clay loam soils with relatively uniform physical structure in undisturbed state, colour ranging from very dark brown to yellow orange. The clay minerals are mainly of the Kaolitic type with low cation exchange capacity, low base saturation, and high acidity with pH less than 6.

Data collection

Productivity data collection

Time studies to determine the productivity and cost of feller buncher (843 J) was undertaken in accordance with generally accepted forest work study procedures (IUFRO 1995). A feller-buncher cycle was divided into the following work elements as defined by (Lanford and Stokes 1996)

1. **Moving to tree**: starts when the feller-buncher finishes the previous cycle and begins moving to the next tree to be cut and ends when forward movement has stopped.

2. **Cutting**: begins when the cutting head is positioned on the tree, cuts and ends when the tree is completely severed from the stump.

3. **Moving to dump**: begins when the feller-buncher moves from the stump area with the felled tree and ends when movement is stopped at the dumping site.

4. **Dumping**: begins when movement to dump has stopped and the felled tree is tilted by the felling head into dump position and ends when the tree or tree bunch

Time recording was mainly focused on work place time (WPT). This is defined as the time spent in performing a task at the workplace time. It is made up of productive or effective time (work element contributing directly to production) and delay times (interruptions in the working cycle). Delays were further subdivided into necessary delay (inevitable interruption due to the nature of the work) and unnecessary delays (those which could theoretically be eliminated by improved supervision and training). Timing was started at the beginning of each work-element and stop watch was snapped back to zero at the end of the work element, elapsed time was read directly from the stop watch and recorded on pre-prepared field form.

Other independent variables were also measured and recorded. These included the slope, tree diameter, tree heights, and the distance between trees. The slope was measured by using a clinometer and recorded in percentage (%), diameter at breast height was measured using a tree caliper and recoded in the nearest centimeters, the tree height, log heights and the moving distances were measured using tape measures and recoded in meters.

Log volume was computed using Huber's formula as shown in equation (1).

$$Lvol = \frac{\pi md^2 L}{4} \qquad \textbf{(1)}$$

Where:

Lvol = log volume (m^3); *md* = log mid-diameter (m); *L* = log length (m).

Cost data collection

Labour, equipment and machine costs (fixed and variable costs) were obtained from both primary and secondary sources. Equipment and machinery costs included: purchase price, depreciation, interest, taxes, oil, fuel, lubricants and insurance costs. Labour costs included direct wages and other indirect costs like incentives and fringe benefits.

Data Analysis

Data were analyzed to establish logging production rates and costs. Both descriptive and regression analysis of data was performed by using Microsoft Excel Spreadsheet. Besides determining the means standard deviation, the range and standard errors of the mean, some regression equations were developed to find out which independent variable have significant influence on productivity of each work element. Coefficient of determination (R^2) was used to determine the amount of influence in the regression equation.

Regression equations were developed for the following work elements: moving to tree, tree cutting, moving to dump with tree and dumping the tree at the landing. For each of the felling element, regression hypothesis was formulated to test if the dependent variables were influenced by the selected independent variables. The independent variables analyzed included: distance to tree, distance to dump, diameter at breast height, stump diameter, slope and merchantable tree height. Using the formulated regression hypothesis, multiple linear regression equations were derived. For convenience of presentation, the following abbreviations or symbols were used to indicate the dependent and independent variables used in the regression equations:

Mvt = moving to tree time, (minutes), Dist = distance to tree, (m)., Dbh = diameter at breast height, (cm)., Mht = merchantable tree height, (m)., Mvd = moving to dump time, (minutes)., Disd = distance to dump, (m)., Dump = dumping time, (minutes), TT = total felling time, (minutes).

Moving to tree

Moving to tree time was envisaged to be influenced by ground travel distance between harvested trees and the slope of the terrain hence the following null hypothesis

$$H_o : Mvt = f\{Dist, Slope\}$$

Cutting

Cutting time involved positioning felling head on the tree and ends when the tree is completely severed from the stump. Cutting time was envisaged to depend on Dbh and slope of the terrain which led to the following null hypothesis:

Total felling time

Total felling cycle time comprised the sum of productive times of the individual felling elements. It is therefore influenced directly or indirectly by those factors which influence the individual elemental times. The following regression hypothesis was formulated for total felling time.

Regression hypothesis for total felling time

$$\mathrm{H_O : TT = f\{Dist, Disd, Dbh^2, Ht^2, Slope\}}$$

The regression equations based on time study data were used to calculate the average production rates for the felling operations as follows:

$$\mathrm{H_o : Cut = f\{Dbh, Slope\}}$$

Moving to dump

Moving to dump begins when the feller-buncher moves from the stump with the felled tree and ends when movement is stopped. Moving to dump is therefore proportional to the surface linear distance to be traversed and the slope of the terrain. For this reason the following hypothesis was formulated:

$$\mathrm{H_O : Mvd = f\{Disd, Slope\}}$$

Dumping

Begins when movement to dump has stopped and the felled tree is tilted by the felling head into dump position and ends when the tree or tree bunch hits the ground (plate1d). Dumping time was therefore expected to depend on the size of the tree.

For this reason the following hypothesis was formulated.

$$\mathrm{H_O : Dump = f\{Dbh\}}$$

$$P = \frac{(T_{vol})(F)(60)}{T} \qquad (2)$$

Where:

P = production rate for a given machine, (m^3/h), *Tvol* = total volume of all logs/trees for a given logging operation, (m^3), *60* is number of minutes per workplace hour, F = proportion measuring productive minutes per workplace hour, T = total productive time (minutes) per trip from the respective regression equation.

$$F = \frac{100 - D}{100} \qquad \textbf{(3)}$$

Where:

F = a fraction measuring the proportion of productive time, D = delay time expressed as percentage of workplace time, %.

The hourly costs, together with production rates were then used to calculate unit production cost as shown below.

$$\text{Unit costs}\left(\text{Tshs}/m^3\right) = \frac{\text{Hourly costs}\left(\text{Tshs}/h\right)}{\text{Production rate}\left(m^3/h\right)} \quad (4)$$

RESULTS AND DISCUSSION

Time distribution among work elements

Table 1 provides summary of the total felling time which included: times for feller-buncher to move to tree, cutting the tree, moving to dump site and dumping of each felled tree. Total felling time per tree ranged from 0.22 to 16.23 minutes and averaged at 0.77 minutes. Results show that the feller buncher used most of the time to move between trees.

This observation could be attributed by the fact that ground had a number of obstacles that included small trees and high stumps left during thinning operations. The undergrowth herbs and small shrubs also provided considerable resistance to the machine movement

. Table 1. Statistics of work elements for feller-buncher felling (n=100)

Elemental time (min)	Mean (min)	Standard deviation	Minimum (min)	Maximum (min)	% of total time
Move to tree	0.360	0.16	0.070	0.817	45
Cutting	0.030	0.001	0.002	0.100	4
Move to dump	0.280	0.150	0.050	0.667	35
Dumping	0.030	0.010	0.020	0.080	4
Necessary delays	0.078	0.972	0.000	15.000	10
Unnecessary delays	0.016	0.145	0.000	2.000	2
Total time	**0.790**	**1.070**	**0.210**	**16.020**	**100**

Estimation of felling production rate

The results showed that feller buncher productivity ranges from 16.45 to 80 m^3/h for trees with Dbh 11 and 32cm respectively. The average productivity was 45.4 m^3/h (Table 2). A study by Benno (2002) reported productivity of 50m^3/h in South Africa and Wang *et al*. (2004) reported a productivity of 35 m^3/h in central Appalachian hardwood forests which are very similar to the results of this study. These production levels were achieved following a combination many things including close supervision and frequent machine maintenance. Observations show that the company management took prompt and appropriate measures to correct for any anomalies in the production sites. For example although the machine could be maintained on site incase of small malfunctions but frequent and intensive maintenance of the machine at the workshops reduces machine breakdown and ultimately resulted into an increased total productive time.

Furthermore, the results indicate that as tree sizes increases in terms of Dbh, the productivity of the feller buncher increases linearly (Table 2). The plausible reason for this could be that, as tree sizes increases in terms of Dbh, tree volume increase and production rate increases

Table 2: Estimated production rates for feller buncher.

Dbh(cm)	Production rates(m^3/h)
11	16.5
12	18.0
13	18.8
14	25.5
15	26.3
16	29.3
17	33.1
18	33.8
19	37.5
20	40.3
21	42.9
22	46.9
23	48.1
24	53.0
25	55.4
26	61.0
27	69.6
28	70.1
29	72.4
Average	**45.4**

Unit felling cost

Based on these results, the fixed costs per scheduled machine hour were estimated to be 37 421 TZS/h while operating cost per machine hour were estimated to be 43 028 TZS/h. The felling unit cost was 2 075 TZS/m^3 (1.5 USD/m^3). The results are in line with other studies reported at central Appalachian hardwood forest on feller buncher felling which indicated a unit felling cost of 2.3 USD/m^3 (Jingxin *et al*. 2004). These results indicate that although feller buncher felling requires much higher hourly cost to operate, its cost per unit volume is compensated by higher hourly output.

Factors affecting productivity of feller buncher for each work element

Move to tree time

Move to tree time was significantly affected by ground travel distance between the trees and the slope (Equation 5). R^2 was lower which indicates that moving to tree time is not well estimated by using moving to tree distance and slope but depends on other factors that were not included in this study and are generally un-measurable and highly variable such factors may include operator skills, health of operators, climatic condition and efficiency.

$$Mvt = -0.01653 + \underset{(0.00133)}{0.007103} \; Dist + \underset{(1.48022)}{7.07} \; Slope \qquad (5)$$

$R^2 = 0.24; \; n = 150$

Tree cutting time

The regression ANOVA shows that cutting time was significantly different among Dbh classes and slope of the terrain (Equation 6). This indicates that Dbh which is a surrogate value for the cross sectional area of a tree, determines the feller buncher cutting time and thus has a direct impact on felling productivity.

$$Cut = -0.03118 + \underset{(0.000169)}{0.00278}\,Dbh + \underset{(0.133428)}{0.574}\,Slope \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$R^2 = 0.69$, $n = 150$

On the other hand the results suggest that slope of the terrain being a significant factor, is the primary determinant of the feller buncher travel stability, particularly when positioning the grappling device on the tree and hence influencing cutting time. Conway (1979) found that if the slope is steep the use of feller buncher lose efficiency to the point of making an operation infeasible on a slope over 35%. This is confirmed by the findings of this study that the average slope of terrain ranging from 0 to 4% improved the efficiency of the grappling devices which resulted into lower felling time.

Moving to dump

The results indicate that moving to dump was significantly affected by distance to dump and slope of the terrain (Equation 7). There were no significant differences in this time element (move to dump) among Dbh, merchantable height and distance to tree. R^2 indicates that moving to dump time can be predicted by using moving to dump distance and the slope of the terrain. In view of this, distance to dump and slope were the significant factors which determine the total tractive efforts required by the feller buncher to move and thus the time required to move to the dump.

$$Mvd = -0.23583 + \underset{(0.00102)}{0.011503}\,Disd + \underset{(1.405031)}{8.617509}\,Slope \qquad \textbf{(7)}$$

$R^2 = 0.508$ $\quad n = 150$

Dumping

No significant differences were found for dumping time among Dbh classes (Equation 8). This indicates that none of the selected variables was statistically significant determinants of dumping time. However, the result suggests that dumping time was probably influenced other factors including the release speed of the grappling device that factors on the loosening and pulling out ability from grappled trees.

$$Dump = 0.2717 + \underset{(0.0493)}{0.0005}\,Dbh \qquad (8)$$

$R^2 = 0.000236$, $n = 150$

Total felling time

The regression equation indicates that among the variables selected for testing, total felling time is best predicted, by distance to tree, distance to dump, Dbh^2, and slope as justified by high value of R^2 (Equation 9). The result are consistent with other published studies which noted that total felling time is best described by Dbh, slope of the terrain, ground travel distances between harvested trees and distance to dump (Mitchell 2000; Jingxin *et al.* 2002).

$$TT = 0.5137 + \underset{(0.003741)}{0.01020}\,Dist + \underset{(0.002983)}{0.098}\,Disd + \underset{(0.000146)}{0.0004}\,Dbh^2 - \underset{(2.191318)}{16.314}\,Slope$$

(9)

$R^2 = 0.554$, $n = 150$

CONCLUSION

The estimated felling production rates ranged from 16.5m^3/h to 80m^3/h with an average of 45.3 m^3/h. Based on these results, the fixed cost per scheduled machine hour were 37 421TZS/h while operating or variable cost per machine hour were estimated to be 43 028TZS/h.The result indicates that the felling unit cost was 2 075TZS/m^3 (1.5USD/m^3).

However, the study has observed that under the conditions studied the most influential factors affecting feller buncher productivity and costs were Dbh and moving distances (i.e. moving to tree and moving to dump).It is concluded that feller buncher is more satisfactory for felling operations in similar stands judged on the basis of felling costs.

REFERENCES

Abdullah, E., Mustafa, Y. and Fatih, T., 2006. Impact of mechanized harvesting machines on forest ecosystem residual stand. *Journal of Applied Science* 6(11): 2414-2419.

Ahlback A.J., 1986. *Industrial Plantation Forestry in Tanzania*: facts, problems and challenges. Forest and Beekeeping Division, Dar es Salaam, Tanzania. 197 pp.

Benno, K., 2002. Mechanization in South Africa an appropriate solution . In: *Proceeding of wood for Africa Forest Engineering conference July2002*, South Africa.161-169pp.

Conway, S., 1979. *Logging practice, principle of timber harvesting system*. Miller Freeman, USA, 416 pp

Dykstra, D.P., 1983. Forestry labour in Tanzania: Learning, compensation and motivation. Professorial inaugural lecture. Division of Forestry, University of Dar es Salaam. Morogoro. 204pp

FAO 1977. *Planning Forest Roads and Harvesting Systems*. Forestry paper 2. Food and Agriculture organization of the United Nations, Rome. 148 pp.

IUFRO 1995. *Forest work study. Nomeclature.Test Edition valid 1995-2000*. International union of Forestry Research Organisations. Swedish University of Agricultural sciences, Department of operational Efficiency , Garpenberg, 16pp

Jixing, W., Long, L. and Joe, M., 2004. Production and Cost analysis of feller buncher and grapple skidder in Central Appalachian hardwood forests. *Forest products Journal* 54 (12): 159-167.

Kellogg, L.D. and Spong, B., 2004. *Production and Costs of Cut-to-Length Thinning: Experience from the Willamette Young Stand Project*. Forest Research. Laboratory., Oregon State University, Corvallis, Oregon. 23 pp.

Lanford, B. L., and Stokes, B. J., 1996. Comparison of two thinning systems. Part 2. Productivity and costs. *Forest Products Journal* 46(1 I/I 2):47-53.

Mlowe, L. M., 2007. Prospects of involving various stakeholders in the management of Sao Hill Forest Plantation, Iringa region, Tanzania. Dissertation for Award of MSc Degree at Sokoine university of Agriculture, Morogoro, Tanzania,125pp.

Mitchell, J., 2000. *Productivities and Costs of Harvesting Small Openings in the Cariboo Forest Region*. FERIC, Vancouver, BC. 1 (22), 8 pp.

Mshimbula, T.J., 1996. Loss of wood during timber harvesting operation in southern paper mill. Faculty of Forestry, Sokoine University of Agriculture. *Forest Record. 63*.

Ngaga, Y.M., 1998. Analysis of Production and Trade in Forest Products of Tanzania. PhD Thesis submitted at Agricultural University of Norway, 93-95.

Philip, E., 2001. Comparison of efficiency and working conditions between privately and past publicly controlled logging operation. A case study of Sao Hill Forest Project. Unpublished MSc. thesis, Sokoine University of Agriculture, Morogoro, Tanzania. 124pp.

Wang, J., Long, C., McNeel, J. and Baumgras, J., 2004. Productivity and cost of manual felling and cable skidding in central Appalachian hardwood forests. *Forest Products Journal 54(12)*: *45-51*.